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EFFECTS OF SLEEP DEPRIVATION ON U.S. NAVY SURFACE SHIP WATCHSTANDER PERFORMANCE USING ALTERNATIVE WATCH SCHEDULES

by

Matthew T. Yokeley

September 2012

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The workload required of personnel onboard U.S. Navy warships continues to increase at a rapid pace. Personnel required to stand watches, in addition to normal work responsibilities, often times find themselves in a position that leads to a deprivation in their total daily sleep. Given the nature of responsibilities placed on U.S. Navy watchstanders, working under conditions of avoidable sleep deprivation is unacceptable.

Using information gained from a predictive performance model instantiated in the Fatigue Avoidance Scheduling Tool (FAST), the optimal watch alternative plan to use is a 3/9-watch rotation, where personnel stand three hours of watch followed by nine hours off. This thesis attempted to quantify the effects of sleep deprivation on performance and to determine how that performance is changed through the use of the 3/9-watch rotation compared to a traditional four section 5/15-watch. Results comparing performance to sleep showed performance did increase with higher sleep levels and indicated better performance for personnel standing watch at certain times of the day. Overall, the 3/9-rotation was not only preferred by the crew, but was shown to have actual measurable benefit in performance.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

BAC	Blood Alcohol Concentration
CCS	Central Control Station
CIC	Combat Information Center
DDG	Guided Missile Destroyer
EOOW	Engineering Officer of the Watch
EPCC	Electrical Plant Control Console
ESS	Epworth Sleep Scale
FAST	Fatigue Avoidance Scheduling Tool
GAMS	General Algebraic Modeling System
IRB	Institutional Review Board
Mean RT	Mean Reaction Time
MSL	Mean Sleep Latency
NREM	Non-Rapid Eye Movement
NSWW	Navy Standard Workweek
PE	Predictive Effectiveness
POD	Plan of the Day
PSQI	Pittsburg Sleep Quality Index
PVT	Psychomotor Vigilance Test
REM	Rapid Eye Movement
RT	Reaction Time
SA	Situational Awareness
SCN	Suprachiasmatic Nuclei
SDRT	Standard Deviation of Reaction Time
SSS	Stanford Sleepiness Scale
TDS	Total Daily Sleep
TSD	Total Sleep Deprivation
WAM	Wrist Activity Monitor

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EXECUTIVE SUMMARY

The ever-looming threat of budgetary reductions and the sizeable costs incurred by the U.S. Navy with regard to personnel have led the service to make drastic cuts to personnel manning. These cuts, while occurring across the Navy, are especially dangerous to an already dwindling surface force. According to the head of Fleet Forces Command, ADM John Harvey, between 2003 and 2009, the U.S. Navy cut nearly 60,000 sailors from its ranks. Growing concerns over the need to "trim the fat" from service budgets leaves personnel high on the list of targets. The result of these cuts however, impact not just the bottom line but the daily watchbills onboard U.S. Navy warships.

Recent studies have shown that personnel manning onboard U.S. Navy frigates and cruisers have led to situations where personnel are receiving less sleep than allotted by the Navy Standard Workweek (NSWW). On average, personnel onboard cruisers achieve two-hours less sleep per week and personnel on frigates nearly nine-hours less per week than prescribed by OPNAVINST 1000.16K- *Navy Total Force Manpower Policies and Procedures* (Haynes, 2007; Green, 2009; Mason, 2009). Because of the reduced manning and the subsequently increased workload, sailors find themselves compromised in their ability to stand an effective watch as prescribed. As such, it is critical that the surface Navy adopt a watch rotation plan that accounts for the natural circadian rhythm of people and balances it with the increasing demands on personnel.

The alternative watch rotation proposed was a three-hour "on," nine-hour "off" rotation for personnel standing a four-section watch rotation. This is commonly referred to as the "3/9-watch rotation." Personnel standing a four-section watch means that there are a total of four distinctly different watch teams comprised of different personnel that rotate through various times of the day at different watch stations.

This thesis poses four questions that attempt to understand, quantify and rectify these effects of sleep deprivation and how the surface community can best employ these alternative watch schedules to its benefit: (1) What is the optimal method of implementing an alternative watch rotation to facilitate forward rotation? (2) Is it possible

to assess vigilance and attention of personnel on these alternative watch rotations? (3) Is the performance of individuals improved using the proposed alternative watch rotations as compared to a conventional rotation? (4) Do crews prefer the conventional watch rotations or the proposed alternative watch rotations?

To answer these questions, volunteers onboard the USS JASON DUNHAM (DDG 109) wore wrist activity monitors for 28-days, over the course of two separate underway periods, and completed self-reporting activity logs detailing their daily activities. They completed specifically tailored survey questionnaires designed to assess the individual feelings and preferences with regard to the watch rotations proposed, as well as psychomotor vigilance tests that recorded each individual's prolonged attentiveness after performing routine watch standing underway.

Results of this study showed that many sailors experienced an increase in total daily sleep using the alternative watch rotations, while others experienced less total daily sleep. Despite this disparity, nearly all participants experienced benefit from stable work-rest patterns associated with the static watch schedules. These stable sleep patterns resulted in higher predicted effectiveness and overall better performance. Improvements in the mean reaction times, standard deviations of reaction times and total number of lapses in the psychomotor vigilance tests were seen throughout.

Even though it was not possible to prove a definitive change in all performance through the use of objective measurement methods, subjective survey results showed positive support for the proposed alternative 3/9-watch rotation. Sailors using this rotation believed they experienced more sleep and felt it was better than the traditional watch rotations currently used throughout the Navy.

Overall, the use of the alternative watch rotations was a success and it was proven that they could be used in actual operational environments onboard surface ships.

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I. INTRODUCTION

A. BACKGROUND

Sleep is one of the most fundamental needs of life. The human body requires sleep not only to rest and repair the body, but to ensure the body operates efficiently and correctly. Not only do all people require sleep to sustain a healthy and fit life, but almost all people have also experienced the negative effects of less-than-adequate sleep. The effects of this sleep deprivation are wide and varying, but are unmistakable and can have disastrous consequences. Sleep deprivation has been compared to alcohol intoxication, with hours of wakefulness equated to blood alcohol concentration (Dawson & Reid, 1997; Lamond & Dawson, 1999), demonstrating that sleep-deprived individuals experience many of the same effects as someone under the influence of alcohol.

Studies have also shown that memory is negatively impacted by sleep deprivation and that decision-making in uncertain conditions, such as those in military operations, is particularly vulnerable to the effects of sleep loss (Killgore, Balkin, & Wesensten, 2006). The impacts on the function of the brain are also well documented with regard to sleep loss. Specifically, the impacts of sleep loss to verbal learning and critical cognitive function—including the effects on short-term memory recognition—have shown that as little as 24 hours of sleep deprivation can impact the ability of the brain to store information in short-term memory (Polzella, 1975). This point is particularly concerning given the nature of operations onboard U.S. Naval warships. During a typical watch, an individual watch-stander is exposed to hundreds of verbal communications in the form of both general information and tactical orders. This information is typically temporary, but any impediment to the processing and storing of such information can lead to dangerously executed orders.

Most personnel onboard ships are required to stand a watch in addition to normal work responsibilities. The workload required of personnel onboard U.S. Navy warships continues to increase at a rapid pace as a result of reduced manning. Often personnel find themselves in a position that leads to a deprivation in their Total Daily Sleep (TDS).

Despite the fact that the Navy adopted the 168-hour Navy Standard Workweek (NSWW), multiple studies have shown the amount of work conducted by personnel onboard ships greatly exceeds the amount allotted in the NSWW (Haynes, 2007; Green, 2009; Mason, 2009). These studies showed that personnel onboard USN cruisers slept an average of two-hours less per week and personnel onboard frigates slept an average of nearly nine-hours less per week than allotted by the NSWW. While the loss of such sleep time over the course of a week may not seem extreme or unreasonable, other studies have shown that as little as one night of sleep deprivation can lead to significantly less effective executive functioning of the pre-frontal cortex (Nillson et al., 2005), thus resulting in lower cognitive performance and less vigilance on the part of personnel.

Other research, using the Fatigue Avoidance Scheduling Tool (FAST) in conjunction with the General Algebraic Modeling System (GAMS), has produced algorithms for optimally scheduling watch rotations onboard ship (Roberts, 2012). These algorithms can produce predictive effectiveness (PE) levels based on the watch rotation implemented and the sleep cycles of the individuals standing watch. Results have shown the PE for personnel standing the 3/9-watch rotation averaged 89.9% compared to 83.4% using a traditional four-section watch rotation. Likewise personnel standing a 4/8-watch rotation had an average PE of 82.9% compared to 82.5% for a traditional three-section watch rotation. While the differences in these PEs seem minimal, they are the averages over time, which indicates that personnel are also highly susceptible to being lower than these PEs at any given time. With higher PEs however, the propensity for any singularly lower PE decreases.

B. OBJECTIVES

This thesis compares the current traditional watch rotations employed onboard U.S. Navy surface ships with alternative watch schedules developed using the FAST-GAMS algorithms (Roberts, 2012) in order to ascertain the vigilance, performance and sleep of watchstanders in an operational environment and, thereby determine if the proposed alternative watch schedule improves vigilance and attentiveness. These objectives are accomplished through the use of subjective measurements, such as surveys

and activity logs, along with objective measures including wrist actigraphy monitor (WAM) data and psychomotor vigilance testing (PVT).

C. SCOPE, LIMITATIONS, AND ASSUMPTIONS

This thesis is focused primarily on the three and four-section watchstanders of the three primary control stations onboard ship—the Bridge, the Combat Information Center (CIC) and the Central Control Station (CCS). However, the Bridge and CCS watchstanders do not exclusively stand watch in the physical space of the Bridge or CCS. Some of these personnel are part of a rotating or "roving" watch, which requires them to move around between various spaces and locations on the ship.

Personnel assigned to the Deck Division, including Botswain's Mates and Deck Seamen, stand watch as both lookouts and Helmsman. Approximately 25% of their watch time is spent rotating to the Aft Lookout position while the remainder of their watch time is actually spent on the Bridge as the Helmsman or Forward Lookout.

Of the participants assigned to the Engineering Department, one of these individuals was assigned as the Propulsion Systems Monitor, which is considered a roving watch. While this position does fall under the responsibility of the CCS, the individual standing this watch is responsible for assessing various systems throughout the engineering plant and reporting back to the CCS. The remainder of the Engineering Department participants stood watch as either Engineering Officer of the Watch (EOOW) or Electrical Plant Control Console (EPCC) operator, exclusively in the CCS.

One of the biggest limitations of this study was the inability to solicit a large number of Engineering Department Personnel. Some of the most interesting preliminary analysis of results came from these personnel, but because of the low number of participants from this department, the results are inconclusive. Another hindrance to having more participants was the focus on three and four-section watchstanders only. Many of the available watch stations onboard DDG-109 fell outside the three and four-section rotations; therefore, these watchstanders were unable to participate. The results of this study are also limited by the short durations of each testing period. Personnel were

exposed to two separate underway periods of only 14-days each; therefore, it did not provide a great deal of opportunity to record the long-term effects of sleep deprivation or of improvements in performance.

Due to timing and funding constraints only one ship was utilized for this study and thus the findings may not necessarily be reflective of the condition onboard all U.S. Navy warships. Since one of the purposes was to assess the ship in an actual operational environment, the study was limited to only those underway time periods that the ship had available. The decision to conduct the research onboard the USS JASON DUNHAM (DDG 109) was ultimately made because of the ships availability and the command leadership's willingness to support the schedule changes and watch rotations necessary for the study. As such, it should be noted that without the express desire and full commitment of the command leadership to accommodate such watch rotations, these rotations may not work onboard other ships.

This study assumes that the volunteers who participated are an accurate representation of the personnel who comprise sailors aboard U.S. Navy warships. It is also assumed that these personnel receive no special treatment or reduced workload in comparison to others in similar positions. This assumption must hold true because if workload were reduced in conjunction with being in this study, the results observed would not be reflective of the actual demands placed on sailors underway.

Unlike the NSWW, this study made no assumptions with regard to the ship being only in a Condition III level of readiness while underway. Again, because the purpose was to assess the actual ability of the ship to implement alternative watch rotations in a realistic operational environment, this study assumed that the ship could operate at any level of readiness at any given time.

II. LITERATURE REVIEW

A. FATIGUE

Fatigue is defined, according to the American Heritage Dictionary, as a "decreased capacity or complete inability of an organism, organ, or part to function normally because of excessive stimulation or prolonged exertion." While the effects of fatigue are readily felt by many, the quantification of fatigue and how it truly impacts personnel is often overlooked. These impacts, for instance, are felt more strongly in shift-workers due to their non-typical work schedules.

One popular metric for quantifying the performance impairments caused by fatigue is to compare it with performance impairments seen in alcohol intoxication. (Dawson & Reid, 1997). The left y-axis of Figure 1 shows the comparison between the number of continuous hours of being awake with an associated relative performance. Along with this, on the right y-axis of Figure 1, is the comparison between relative performance and the associated blood alcohol concentration (BAC) levels. It can be seen that there is a direct correlation between an associated level of performance and a corresponding BAC. Both performance and BAC are negatively affected overtime and wane with increasing hours of wakefulness.

This correlation in performance between prolonged wakefulness and blood alcohol concentration presents a frightening prospect when examining the potential impact of sleep deprivation on U.S. Navy sailors. In this context, personnel exposed to prolonged periods of sleep deprivation may find themselves operating weapon systems with the same relative performance as an individual who is above the legal intoxication limit for operating a motor vehicle. Such periods of prolonged wakefulness are generally quite common in sailors standing underway watches using existing watch rotation practices. One study has shown that personnel working in "topside" positions—those personnel standing watch on the Bridge or as Lookouts—during Operation Enduring Freedom received an average of only 4.74-hours of sleep per day (Nguyen, 2002).

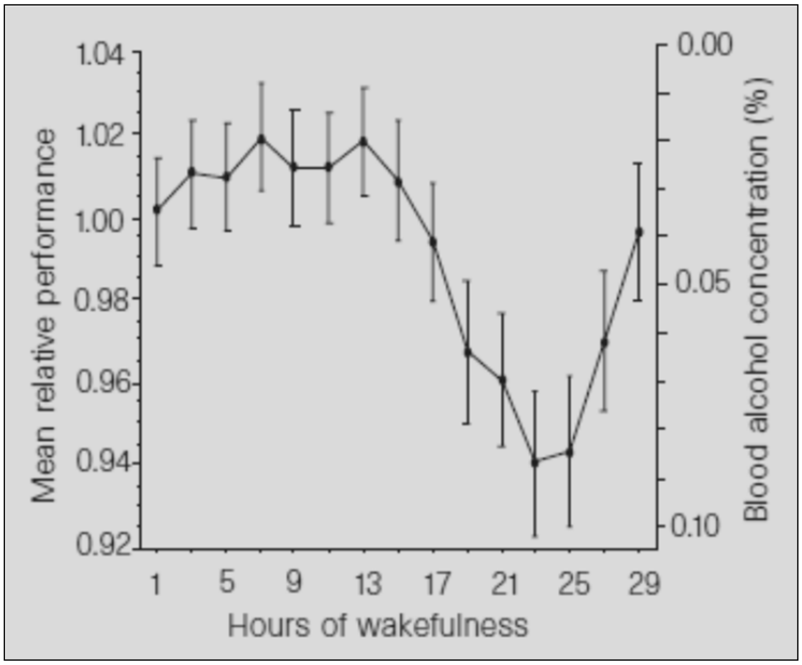

Figure 1. Relative Performance and Percent Blood Alcohol Concentration (From Dawson & Reid, 1997)

Studies have also shown that memory is negatively impacted by sleep deprivation and that decision-making in uncertain conditions, commonly experienced in military operations, is particularly vulnerable to sleep loss (Killgore, Balkin, & Wesensten, 2006). The negative impacts on the function of the brain with regard to sleep loss are also well documented. Specifically, the impacts of sleep loss on verbal learning and critical cognitive function, including the effects on short-term memory recognition, have shown that as little as 24-hours of sleep deprivation can impact the ability of the brain to store information in short-term memory (Polzella, 1975). When individuals are exposed to periods of fatigue, their bodies have two competing systems working within them to cause decreased performance. The involuntary drive of the body to rest, which is part of the circadian rhythm discussed later, and the top-down drive to maintain alertness are both acting on the body simultaneously. The counterproductive actions of these sleep-initiating and wake-maintaining systems lead to unstable sustained attention and ultimately manifest in decreased performance (Basner & Dinges, 2011).

The effects of fatigue on grammatical reasoning, vigilance response, vigilance accuracy and tracking accuracy are equivalent to a blood alcohol concentration of 0.10 in less than 25.1-hours of continuous wakefulness (Lamond & Dawson, 1999). Aside from the direct impact of fatigue on performance, personal risk taking decisions are significantly impacted by fatigue. Personnel exposed to as little as 23-hours of sleep deprivation are willing to take more risk than they ordinarily would when considering a potential gain, but less risk when they were considering a potential loss (McKenna, Dickinson, Orff, & Drummand, 2007).

However, the concern here goes beyond the impacts on the brain and the individual's ability to work effectively. Great consideration must be given to the fact that individuals experiencing these problems are unable to identify that there is a problem.

B. SLEEP

While fatigue is the central point of interest when evaluating the performance decrement of personnel, the root issue behind fatigue is a lack of sufficient sleep. Again, according to the American Heritage Dictionary, sleep is "a natural periodic state of rest for the mind and body, in which the eyes usually close and consciousness is completely or partially lost, so that there is a decrease in bodily movement and responsiveness to external stimuli" (Houghton Mifflin Harcourt, 2011). Due to the complexities surrounding the various combat and engineering systems onboard modern U.S. Navy warships, the need for sailors to obtain an adequate amount of sleep is critical to their successful operation of the various system entrusted to them. Unfortunately, the opportunities to obtain these necessary levels of rest are often less than desired.

Individuals suffering from sleep deprivation are frequently unaware of such impairments and are incapable of accurately self-assessing the anticipated level of performance decrement associated with a loss of sleep (Dorian et al., 2003).

The human sleep cycle is divided into five stages of sleep that are further divided into the two categories of Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM). REM is stage two of the sleep cycle and NREM comprises the other four (Miller & Firehammer, 2007). Figure 2 is a graphical representation of the breakdown of

the five stages and how people progress into and out of each stage throughout a typical eight-hour sleep cycle. Each person starts off in stage one of the sleep cycle and as time continues, they progress into the other stages. People transition into REM sleep before proceeding into the remaining four stages of NREM sleep. The graph shows that people progress into deeper levels of sleep as they move from REM to stage four sleep. Approximately every 90 minutes, an individual completes one sleep cycle, which takes them from REM to stage four and back to REM sleep. Once individuals return to REM sleep, they have reached a "window" that allows them to be awakened. If they are awakened from the REM stage, they will feel the most rested. Waking in stage two, three or four will result in a less rested feeling. These sleep cycles repeat for approximately eight hours, when the individuals exit REM sleep back to stage one and awaken.

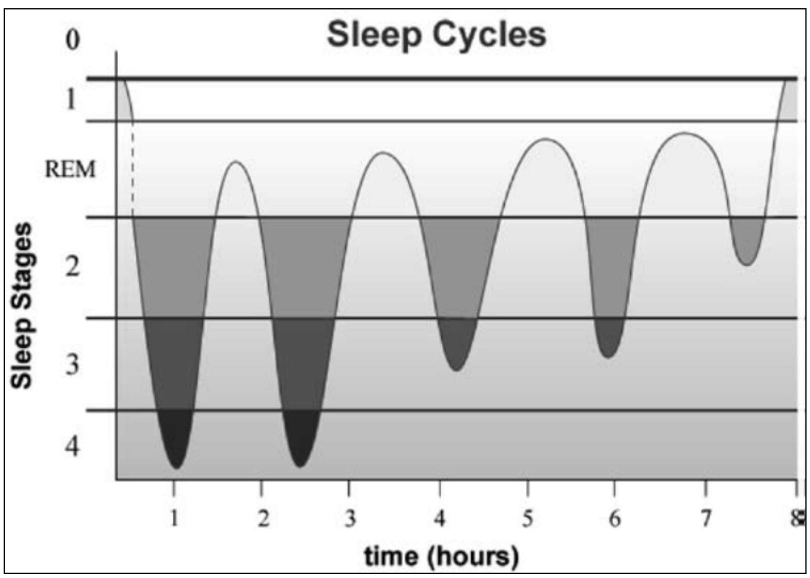

Figure 2. The Five Stages of an Eight-Hour Sleep Cycle (From Miller & Firehammer, 2007)

Deprived of one of these sleep stages, an individual experiences what is known as a "partial sleep deprivation." Someone who is awake continuously without proper regenerative sessions of sleep experiences what is known as total sleep deprivation (TSD) (Miller & Firehammer, 2007). It is TSD that is the most dangerous to the individual

because in a mere 24-hours of TSD, personnel experience higher levels of sleepiness on the Stanford Sleep Scale (SSS) and significant decreases in the cerebral metabolic rate for glucose in several cortical and subcortical structures of the brain that impact alertness, attention and higher-order cognitive functions (Thomas et al., 2000). This indicates a significant decrease in the brain's total ability to perform higher-level brain functions and to maintain desired levels of vigilance after only one-night of sleep loss. Personal planning, organization, multi-tasking and prioritization abilities are also negatively affected after only one night of TSD (Nillson et al., 2005).

As the amount of sleep loss increases, the number of micro-sleeps—sleep attacks and lapses in cognition—also increases. TSD has tremendously negative effects on the endogenous biological clock located in the suprachiasmatic nuclei (SCN) of the hypothalamus (Durmer & Dinges, 2005). Known simply as your "biological clock," the SCN not only compels the body to go to sleep but is also responsible for regulating wakefulness and ultimately generates a circadian rhythm that is unique to each individual.

C. CIRCADIAN RHYTHM

Each individual has a circadian rhythm that regulates his or her sleep patterns. This is defined as "a daily rhythmic activity cycle, based on 24-hour intervals, that is exhibited by many organisms." Sleep can be modeled as a simple two-process model consisting of a sleep homeostatic process and a circadian process that interact with each other to determine the timing of sleep onset and offset, as well as the stability of waking neurocognitive functions. The circadian process represents the daily oscillatory modulation of the thresholds that trigger sleep (Durmer & Dinges, 2005). Individuals normally have an established rhythm that determines when they to go to sleep and when to wake up each day. In shift workers; however, there is often a conflict between displaced work hours and the output of the biological clock, which may cause health-related issues (Åkerstedt, 2002). These issues are directly related to the varying nature of work times.

Since the circadian rhythm determines the timing of sleep onset and offset, it is responsible for the amount of total sleep required of people and when they will receive that sleep. Figure 3 shows that as people age, the time required to sleep lessens and the time of sleep shifts. As can be seen, the optimal sleep time for adolescents and young adults is between the hours of 2300 and 0800. The amount of total sleep time required is about 8.5–9.25 hours; however, not everyone sleeps the same amount. Research has shown that individual differences in sleep requirements can vary by as much as two-hours between people who are considered "morning types" and those considered "evening types" (Kerkhof & VanDongen, 1996). Individuals have a predisposition toward varying sleep patterns based on their natural circadian rhythms. In the case of morning types, they require less total sleep on average and have more consistent sleep start and end times. Evening types, on the other hand, typically require a greater amount of total sleep, but are often in a state of sleep deprivation because they go to bed later and often must still awaken as early as their morning-type counterparts. The evening types also have a more varying sleep start time than morning types, which only compounds the issue of not receiving enough quality sleep (Taillard, Philip, & Bioulac, 1999).

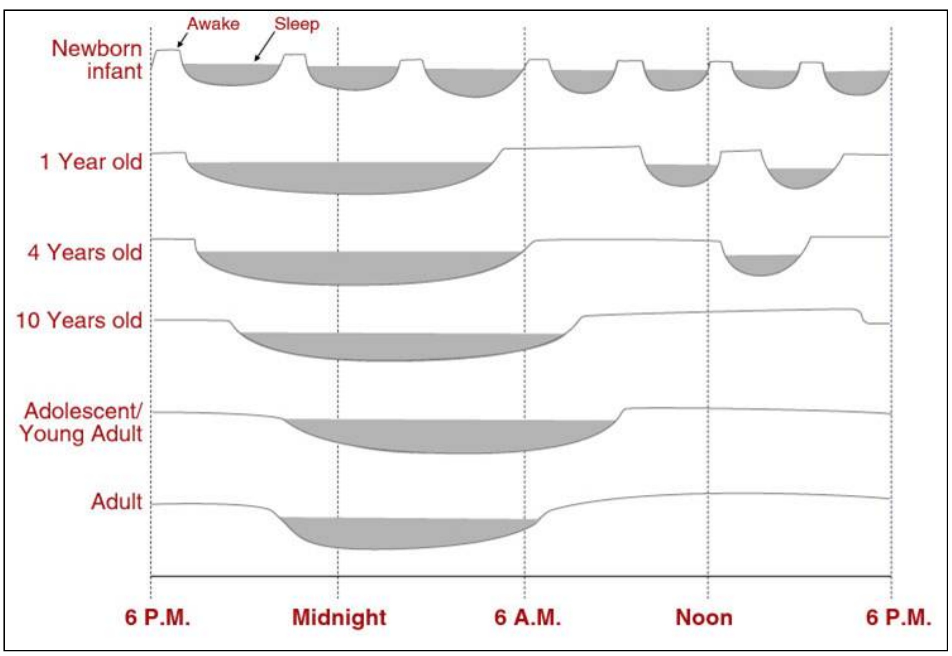

Figure 3. Human Sleep Patterns by Age (From Miller & Firehammer, 2007)

It can clearly be seen that some individuals require a greater amount of sleep than others and the timing of that sleep is critical to their performance. Current Navy culture however, does not take these differences into consideration. Daily routines and watch rotations are tailored more toward individuals with a morningness preference, is putting individuals with eneningness preference at an immediate disadvantage when it comes to receiving the amount of quality sleep expected and needed to perform adequately onboard ship. These same sailors with an eveningness preference are strong candidates for night shifts however. Not accounting for these differences is an important factor to note because it leads to many sailors not receiving the required amount of sleep their bodies naturally need. This issue is further complicated by the fact that these same sailors are not receiving the required amount of sleep in accordance with existing naval instructions (Green, 2009; Haynes, 2007; Mason, 2009).

D. NAVY STANDARD WORKWEEK (NSWW)

The U.S. Navy implemented the NSWW with OPNAVINST 1000.16 in an effort to determine manning requirements for ships. After estimating the amount of work required for a ship to optimally regulate the time sailors spend conducting various activities. The most recent version of this instruction—1000.16K—defines the NSWW as "the total times expressed in average hours per week that are available per person to accomplish the required workload (including watches) of the various types of Navy units." These amounts are key elements in determining Navy manpower requirements onboard ships. As previously mentioned, the NSWW assumes that ships at sea are operating in Condition III with a three-section watch rotation. Table 1 outlines the hours allotted for each category of activity in the NSWW.

OPNAVINST 1000.16K is a guideline stating that personnel on ships at sea should be receiving about 56-hours of sleep per week, which equates to exactly eight hours of sleep per night. Previous studies have all concluded, however, that sailors frequently do not receive the eight hours mandated. In one study it was found that, on average, Chief Petty Officers onboard U.S. Navy cruisers, during the Rim of the Pacific Exercise, slept only 6.26-hours per night while Officers (O-4 and above) slept only 6.38-hours per night. Junior enlisted personnel on these ships (E-1 through E-3), however,

received 7.83-hours of sleep per night (Mason, 2009). A similar study onboard frigates revealed that personnel slept an average of only 6.71-hours per night (Green, 2009). It is clear from this research that the existing construct of work-rest hour division is not working within the surface community.

In other research onboard the USS CHUNG HOON, it was discovered that 85% of personnel worked greater than the 81-hours of “available” work time in the NSWW while more than 50% of personnel worked greater than 95-hours per week (Haynes, 2007). The significance of this information in relation to the amount of sleep that personnel receive is based on the fact that there are only 168-hours in a week. If personnel work for periods of time that far exceed the NSWW allotted amounts, they will often make up for this extra work time by sleeping less.

Total Weekly Hours Available	168 hrs
Non-Work Time	
- Sleep (56 hrs)	87 Hours
- Messing (14 hrs)	
- Personal Needs (14 hrs)	
- Sunday free time (3 hrs)	
Ship Standard Workweek Hours Available	81 hrs
Training Time	7 hrs
Service Diversion Time (Quarters, inspections, administrative matters, etc.)	4 hrs
Total Productive Workweek Time Available	
- Watchstanding (8 hrs * 7 days = 56 hrs)	70 hrs
- Non-watchstanding (14 hrs)	

Table 1. Allocation of Hours per Sailor per Week Based on the Navy Standard Workweek (After OPNAVINST 1000.16K)

E. SHIFTWORK

The concept of a rotating watch is not unique to the Navy. In fact, many private-sector careers are based on some form of rotating assignment or shift. It is well documented that in shift workers, the sleep after a night shift usually begins about 30-60 minutes after the completion of the shift. The sleep that is obtained during these periods is, however, significantly reduced in quality and duration by two to four hours on average (Åkerstedt, 2002). This same shiftwork issue faces many sailors onboard ships when they complete watches such as the 2200–0200 watch and then only receive sleep from about 0300–0700. Working night watches or rotating watches daily in this manner causes the individual to lose out on adequate sleep. A loss of this consistent and contiguous sleep is another cause for disruption in the circadian rhythm (Minors & Waterhouse, 1981). The effect of these shortened periods of sleep deprivation in shift workers ultimately has the same impact as TSD. Individuals operating on 4.5 hours of sleep per night will experience TSD effects in as little as one week (Åkerstedt, 2002). The body's natural response to this lack of sleep is the circadian system's attempt to force individuals to sleep, which is what results in a loss of alertness and vigilance.

The problems associated with shiftwork rotation are not confined to those individuals who rotate daily. In the medical community, rotations often occur on intervals of days or weeks. One study showed that 20% of nurses who worked night shifts for eight shifts or more per month received only five-hours of sleep on average and 60% received between five and seven hours (Gold et al., 1992). Some would say that the requirements of personnel in the medical communities do not represent those of military personnel; however, it is in reality a very close comparison. Medical residents often work in excess of 80-hours per week and often experience at least one day per week where they are required to operate for 24 hours or more without rest (Weinger & Ancoli-Israel, 2002). Other research in the medical community related to sleep deprivation closely mirrors the operating conditions of senior Navy leadership including ship captains, Executive Officers and Department Heads. These studies have shown that surgeons who were administered tests each evening and morning, after having sleep interruptions every three hours, had a higher number of mistakes in simulated surgeries. As a result, the time it

took them to complete a specific medical procedure designed to stop bleeding tissue rose significantly (Taffinder, McManus, Gul, Russel, & Darzi, 1998). These studies help corroborate the fact that the conditions under which U.S. Navy sailors operate is an environment that sets them up for failure in terms of being able to maintain vigilance in not only their watch standing, but in performing their everyday jobs.

Other research however, says that prolonged exposure to shiftwork may not pose a long-term detriment to sleep. A biophysical recording, designed to assess changes in sleep, was recorded on twenty shift-workers over a period of two years. This study reported that a three section work rotation did not affect sleep in experienced shift workers (Åkerstedt & Kecklund, 1991). This finding would tend to indicate that shipboard personnel should not have issues with the rotating watch, but the difference is that the experience levels of many sailors vary greatly from no time at sea to more than a decade at sea. Also, this particular shiftwork does not translate precisely to the shiftwork experienced by sailors. The time in between underway operations may vary by days, weeks or months, which does not provide sailors with continuity in the watch rotation, so they never have the opportunity to become completely accustomed to it.

F. PSYCHOMOTOR VIGILANCE TESTING

Psychomotor vigilance testing or PVT has become a standard for monitoring the vigilance performance of individuals; specifically, measuring impairment on performance during conditions of sleep deprivation. First introduced in the mid-1980s as a tool to assess the sustained attention of an individual (Dinges & Powell, 1985), a number of studies have validated its ability to assess sleepiness in subjects through a variety of operational and experimental settings. The use of reaction time testing to determine the behavioral and cognitive effects on personnel habits has been used since the late 1800s (Dorrian, Rogers, & Dinges, 2005) because of the simplicity in the testing and the ability to readily detect changes without the confounding effects of aptitude and learning (Basner & Dinges, 2011). As previously discussed, when the body experiences an increase in fatigue it has two competing internal systems that impact overall performance. This deterioration in performance will ultimately manifest itself in the form of longer reaction times occurring stochastically during the PVT (Basner & Dinges, 2011).

While research shows that the PVT is a valid means of determining reaction times (RT), the question remains whether there are physiological changes in the brain that can be observed and correlated to PVT test performance. Research has shown that such a connection does indeed exist with subcortical and cortical regions of the brain having greater activity during optimal performance in well-rested individuals (Drummond et al., 2005). In their study, quicker reaction times are associated with greater electrophysiological activity within various regions of the brain, indicating an actual physical response that links sleep deprivation and reaction times. The PVT assesses and individual's ability to maintain attention and respond in a timely manner to signals. The PVT's ability to accomplish this, while meeting all the criteria of a good test, makes it a valuable test measure (Dorrian, Rogers, & Dinges, 2005), but the question of its validity in an operational setting still remains.

Since its inception, the PVT has had two major drawbacks to its use—its duration and scoring metrics. The test time period is a point of concern when conducting research in an operational setting because it is typically a ten-minute test, which is a great deal of time in a real world setting. Use of the PVT in an operational environment has not always been seen as practical for this reason. Previous testing on the alertness of pilots and the effects of napping proved that use of the PVT was difficult in operational settings (Rosekind et al., 1994). However, simply reducing the length of the test to account for this deficiency poses its own problems. Study has shown that lowering the total PVT time may lower its sensitivity to the effects of sleep loss on performance (Mullaney, Kripke, Fleck, & Johnson, 1983). Further research has however, contested this and instead has shown that shortened versions of the PVT are just as valid as the full ten-minute test. These two and five-minute versions of the PVT test indicate a significant decline in performance can be detected (Loh, Lamond, Dorian, Roach, & Dawson, 2004).

The disparity amongst researchers with regard to the scoring metrics of the PVT is the second big issue. Between 1986 and 2011, at least 141 articles related to PVT research were published and each one showed great variability with regard to the outcome metrics (Basner & Dinges, 2011). While some metrics are more common than others, these inconsistencies in results lead to trepidations with regard to the validity of

PVT metrics. Table 2 lists the most common measurement metrics reported and the frequency with which they occur in PVT research.

Measurement	Frequency	Measurement	Frequency
Number of Lapses	66.7%	Slowest 10% of RT	19.9%
Mean Reaction Time	40.4%	Slowest 10% of 1/RT	12.8%
Mean 1/RT	30.5%	Number of False Starts	9.2%
Fastest 10% of RT	29.8%	Fastest 10% of 1/RT	5.0%
Meadian RT	28.4%	Lapse Probability	23.4%

Table 2. Frequency of PVT Metrics Reported in Research from 1986–2011 (From Basner & Dinges, 2011)

Concerns over the use of a portable PC based PVT have also been dispelled. Research conducted by the Walter Reed Army Medical Hospital showed the validity of a portable PVT that can be used in an operational environment. In an experiment where the PVT was conducted on a Palm Pilot device, it was shown that using portable versions of the test revealed the same reduction in performance as the standard PVT reaction test (Thorne et al., 2005).

Research conducted to validate the shorter PVT, for example, was completed using the mean reaction time (Mean RT), Lapse Percentage, Fastest 10% of RT, and Slowest 10% of RT (Loh, Lamond, Dorian, Roach, & Dawson, 2004). Other research attempting to maximize sensitivity of the PVT, however, used Median RT, Mean RT, Fastest 10% of RT, Mean 1/RT, Slowest 10% of 1/RT, Number of Lapses, Lapse Probability (number of lapses divided by the number of valid stimuli, excluding false starts), Number of False Starts, and a Performance Score (defined as one minus the number of lapses and false starts divided by the number of valid stimuli) (Basner & Dinges, 2011). These two research efforts alone show the differences in PVT metrics, yet both attempt to show maximum sensitivity in the PVT. Despite these differences though, research has proven the validity and reliability of the PVT in capturing the

neurocognitive effects of sleep loss without being confounded by unrelated inter-subject and intra-subject variation (Dorrian, Rogers, & Dinges, 2005).

To echo earlier comments about the inability of individuals to assess their own sleep induced impairment, it has been shown that in one-week worth of simulated night shifts, individuals experience significant decrease in PVT performance during night shifts and, to make it worse, these individuals only have a moderate ability to assess their own impairment (Dorian et al., 2003).

G. SURVEYS

The use of surveys to research human behavior has become quite commonplace over the last 75 years (Dillman, Smyth, & Christian, 2008). The inability to accurately measure human factors with objective measuring devices has created a gap in data collection that can only be filled with more subjective measures. Sleep quality, for instance, has become an accepted clinical construct in recent decades; however, the quantification of that construct has been difficult to define. The elements that comprise an individual's sleep quality such as sleep latency, duration and number of arousals may vary greatly from person to person and is difficult to directly correlate (Buysse, Reynolds, Monk, Berman, & Kupfer, 1988).

Great care must be taken when working with surveys because of the tendency of survey structure to influence the results. It has been shown that the format of response scales systematically influence respondent answers (Tourangeau, Rips, & Rasinski, 2000). In crafting these questions, survey designers must also be concerned with what has been coined as the "priming effect." This phenomenon is noted when job related survey questions raise awareness of other job related issues that may not have been thought of otherwise (Salanick, 1984). It is therefore important that surveys used be designed to elicit the responses needed in the most efficient manner possible.

The Pittsburg Sleep Quality Index (PSQI) is a self-rated questionnaire that provides a validated means of identifying sleep quality disturbances over a 30-day period (Buysse, Reynolds, Monk, Berman, & Kupfer, 1988). The PSQI is used to distinguish between "good" and "poor" sleepers by taking scores from a series of categories to

develop an overall sleep quality score. The Epworth Sleep Scale (ESS) is designed to determine how likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired. It has become a standard for subjectively measuring the sleepiness of individuals (Nguyen et al., 2005); however, other research indicates that the ESS may not provide an accurate correlation with mean sleep latency (MSL) (Chervin & Aldrich, 1999). Individuals indicate on the ESS the level of sleepiness they believe they are at, but, as mentioned earlier, the ability of people to self-rate sleepiness is not always accurate.

III. METHODOLOGY

A. STUDY DESIGN

1. Overview

Two basic requirements were identified as necessary to ensure success of this study. First, it was vital to find a U.S. Navy ship that could support data collection during actual underway operations. It was critical that a single ship be identified for this purpose. The idea of executing two separate schedules on two different ships would introduce potentially confounding variables that could ultimately cloud results. In a fortunate turn of events, the leadership and crew of the USS JASON DUNHAM (DDG 109) agreed to participate in the two phase study.

The second condition required for study success was the need for two separate data collection periods in order to compare differences in results between the proposed alternative watch schedules and the traditional schedules. This provided a repeated measures, within-subject design allowing for comparison of individual changes in performance over time and between the two watchstanding schedules. The first underway was designated as the "baseline" period and the second underway as the "test" period. During the baseline period, participants completed a series of written surveys designed to assess their normal sleep patterns, individual sleep quality, and personal feelings toward existing watch schedules. DDG-109 continued to operate on its pre-existing watch rotation schedules while participants took part in the data collection.

During the test period, DDG-109 used the alternative 3/9 and 4/8 watch rotations for both four and three-section watches, respectively. The study participants engaged in normal underway operations while using the new watch rotations and their sleep and psychomotor vigilance test (PVT) data were collected to compare against their baseline data.

After working with the ship's leadership, it was determined that two underway periods already in the ship's schedule would be the prime data collection periods. Each underway period offered exactly 13-days of data collection and 37-days in between each

underway. The baseline period was from 23 January to 5 February 2012 and the test period was from 12-25 March. Both of these underway periods were part of the work-up training for the ship in preparation for her impending deployment.

2. Variables

Much thought was given to the impact of the various potential variables within this study. When conducting research on human subjects, the "human factor" has a pivotal role. It was important to identify potential factors that could skew the results and try to mitigate their impact. Because the study was being done in an operational environment with working individuals, many of the possible confounding factors could not be regulated. However, these factors were given great consideration before beginning the study.

a. Dependent Variables

There were two major dependent variables identified as the most important factors of this study. As previously mentioned, the intent was to assess the amount of sleep participants received and the vigilance each participant had when standing watch. As such, these two goals became the two dependent variables because the objective was to determine if the alternative watch schedules had any effect on them. Other dependent variables included the personal attitudes and opinions of the crew toward the various watch rotation schedules.

Another dependent variable was identified, after the data collection period, by the leadership of the JASON DUNHAM. The situational awareness of each individual over the length of the study was called into question. This variable was not considered as a separate variable before the study began and it was difficult to measure such a subjective factor. However, surveys administered at the completion of the test period specifically asked individuals assess their ability to develop proper situational awareness using the new rotations. Since this variable was not identified prior to the test period, it is difficult to determine whether or not there were changes in situational awareness between the underways. Future research should be conducted to more adequately assess how situational awareness is impacted by the change in watchstanding schedules.

b. Independent Variables

The first independent variable was the watch rotation itself. By altering the two watch rotations to use the 3/9 and 4/8-rotations, then monitoring the results of the dependent variables, it would be possible to determine if they did indeed have an influence. A graphical comparison of the traditional three and four-section watch rotations and the alternatives during a 24-hour period is shown in Figure 4.

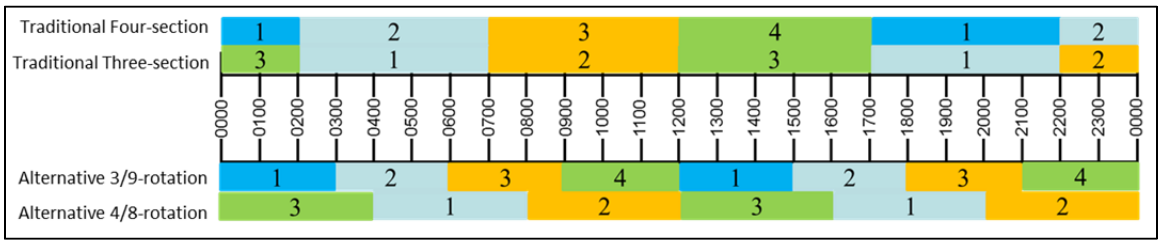

Figure 4. Graphical Comparison of Traditional Three and Four-Section Watches to the Proposed Alternative Watch Schedules

In order to mitigate some of the human element in the independent variable, comparisons were made between the same individuals over the two underway periods. Analyzing the data in this manner would help eliminate some of the possible confounding issues such as differences in individual motivation, sleep habits, job satisfaction, collateral duties, morale, etc. Any one of these could be a significant influencing factor in assessing human performance that could alter the dependent variable outcomes.

3. Institutional Review Board

The objectives and methodology of data collection for this study were submitted to the Naval Postgraduate School Institutional Review Board (IRB) for review and approval. The IRB determined the study and its methods posed little risk or inconvenience to the individual participants and the research was approved.

Prior to beginning the study, participants participated in a recruitment process where they were briefed on all aspects of the study. This briefing included a detailed description of the requirements of the individuals, the data collection methods, and any

potential inconveniences or discomforts participants may experience. Participants were also told that participation was completely voluntary and that no reprisal would be given for declining to participate. All participants signed consent forms indicating their intention to participate in the study. A copy of the NPS Consent to Research Form can be seen in Appendix A.

B. PARTICIPANTS

As mentioned earlier, the participants of this study consisted of three and four-section watchstanders from the major shipboard controlling stations. During initial recruitment of participants 34 crewmembers volunteered. Two of these individuals, however, declined to participate in the second round of testing, for unspecified reasons. A third participant was unable to complete the study due to personal matters that did not allow this individual to be underway during the test period. In the end, only the data from the remaining 31 participants was able to be used. Since a key component of the study was an analysis of the variations in performance between each crewmember, it was critical that there be continuous data for participants across both underway periods.

It should be noted that while 34 total participants did participate in the study, several participants chose not to participate in certain portions of the study. For instance, some may not have completed written surveys, while others may not have completed PVTs as directed. Throughout this thesis there may be instances where the total number of participants for a specific data set do not add up to the total number of participants. These inconsistencies are the result of incomplete data from all participants.

1. Demographics

The 31 participants represented approximately 11% of the total crew. Figure 5 shows the total number of participants by rank and gender. Just over two-thirds of the participants were enlisted and approximately 23% were female. Figure 6 shows the total number of participants from each of the ship's departments. Aside from the ranks, which ranged from E-2 to O-2, and genders of each participant, the time in service for each category is also fairly representative of the total ship's population. Years of sea time for all participants ranged from 6 months to 11 years.

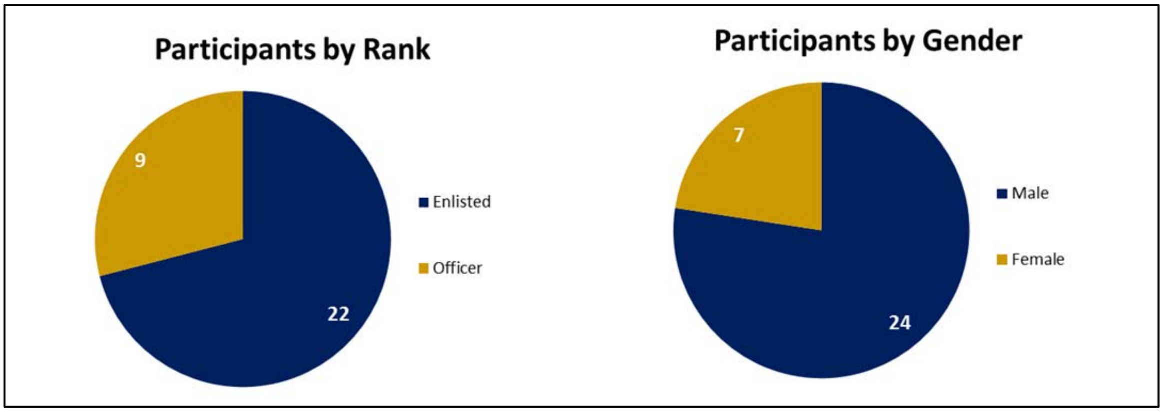

Figure 5. Study Participants by Rank and Gender

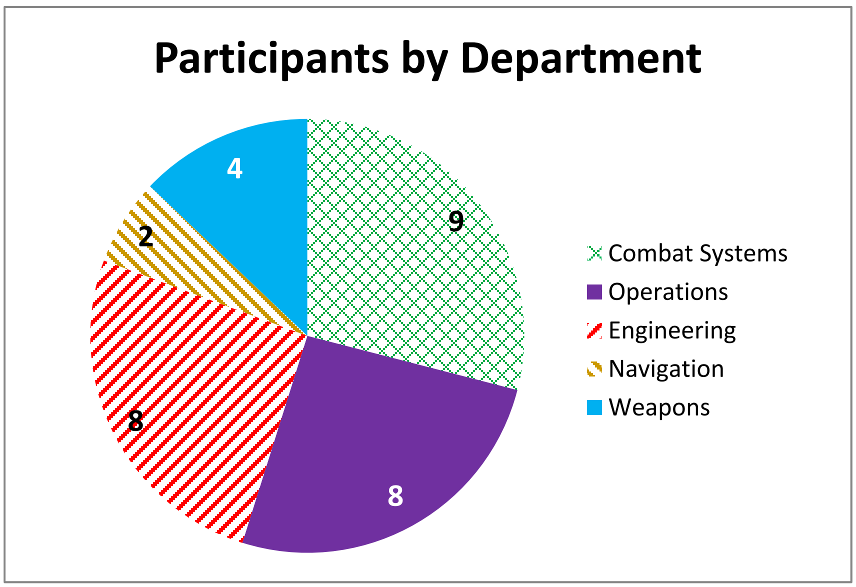

Figure 6. Study Participants by Department

2. Pittsburg Sleep Quality Index (PSQI)

All test participants completed the PSQI after agreeing to participate in the study. The PSQI estimated the overall sleep quality of the individuals for the 30-day in-port period prior to the baseline underway period and was tabulated using the scoring guide found in Appendix H. The results of this particular survey were both interesting and

troubling because they indicated that an overwhelmingly large portion of test subjects have a predisposition to "poor" sleep quality. Figure 7 shows the breakdown of respondents' overall PSQI scores.

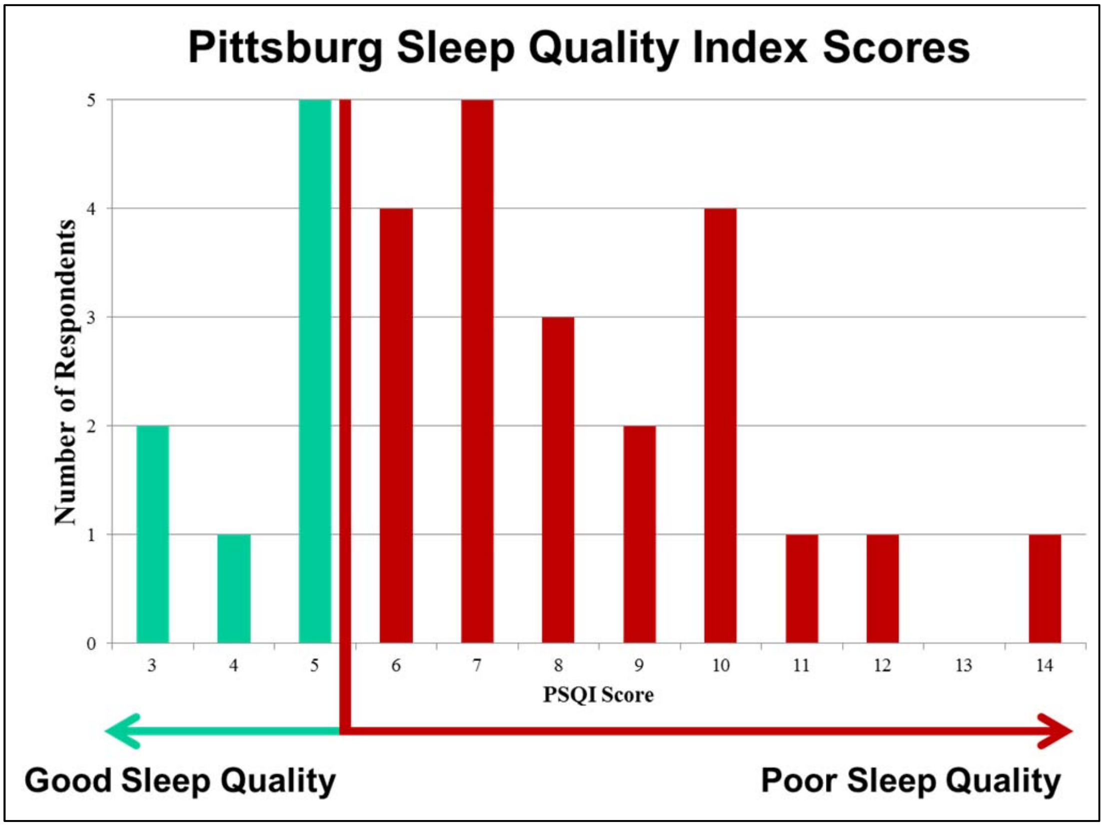

Figure 7. Participant's Overall Scores on the Pittsburg Sleep Quality Index

For the PSQI, receiving an overall score of greater than five indicates that, on average, an individual has poor sleep quality in comparison to the normal population. In this case, 75% of the study participants are noted as being predisposed to poor sleep quality prior to the beginning of the study. We are unable to determine if the other Sailors on DDG-109 experience a similar incidence of sleep problems. To ascertain that information, we would need to administer the PSQI to all crewmembers; however, we assume from the relatively diverse cross section of study participants that most crewmembers would score in the higher PSQI range. We therefore assume that such sleep problems are not unique to the study respondents and the results can be extrapolated to

the remaining crew of DDG-109. The PSQI survey asked respondents to address their sleep for the 30-days in-port, prior to the underway time.

3. Epworth Sleep Scale (ESS)

The ESS was also given prior to the baseline period. This survey was designed to record an individual's self-assessment of their likelihood to sleep in eight different situations. These situations represent a variety of activities that an individual is likely to experience at some point during their day. While the situations are inherently geared toward an individual not underway, it is relatively easy to correlate these situations to activities one might be engaged in onboard a ship. Figure 8 shows the results of each of the eight scenarios asked about.

The results of the ESS did not indicate any unusual concerns over the pre-disposition to sleepiness of the study participants. As such, it was anticipated that there would be no effect on the study findings as a result of using these individuals.

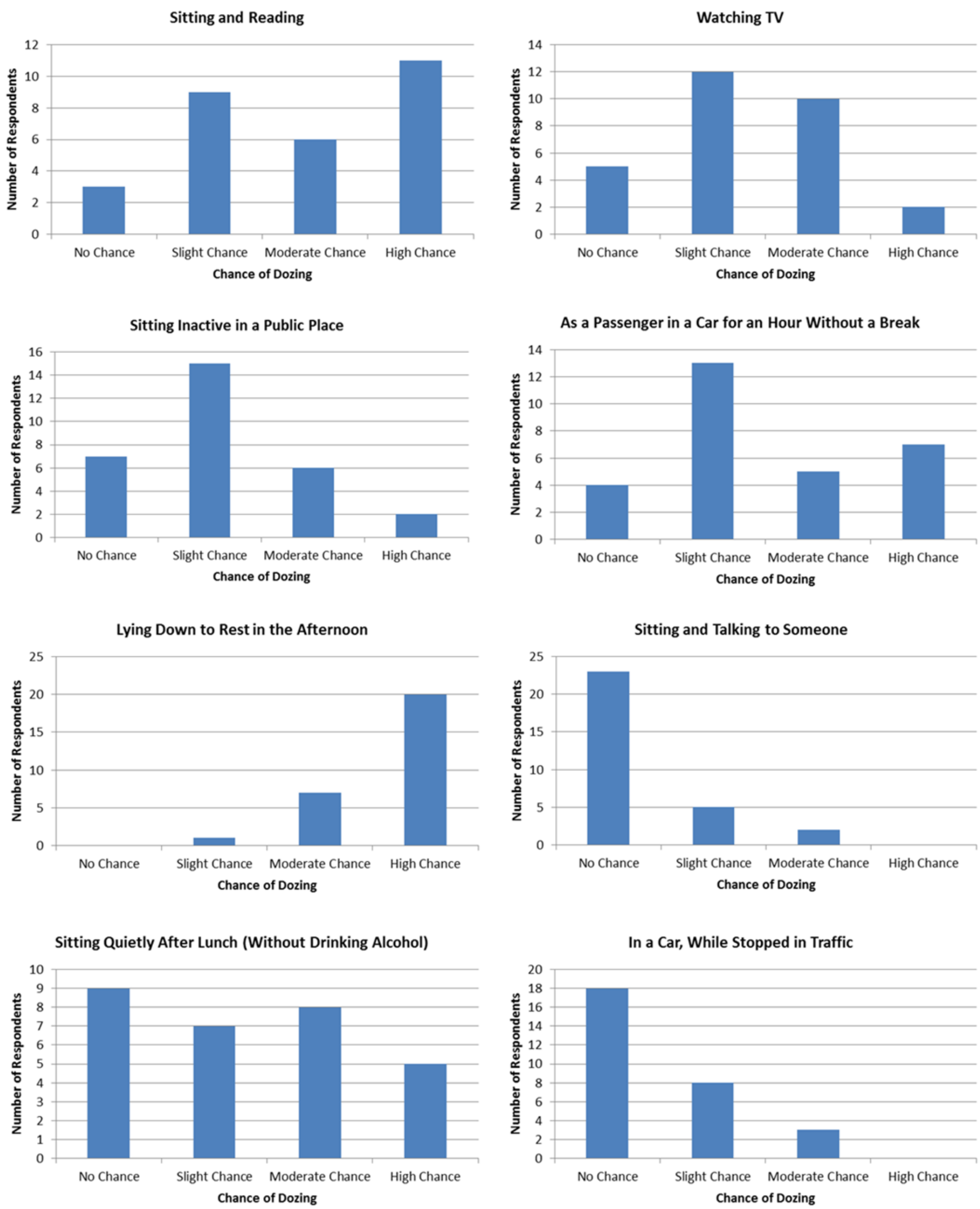

Figure 8. Participant Responses to the Epworth Sleep Scale

C. STUDY APPARATUS

1. Actigraphy

The actigraphy data was collected using the wrist activity monitors (WAM) that each participant wore during both underway periods. The WAMs recorded the amount of sleep each participant received. During each one minute epoch, the WAM recorded the number of “counts” which indicates the total amount of activity detected during that period. WAMs for the baseline period were preset to begin recording at 0800 on 23 January and to terminate data collection 14-days later. The WAMs for the test period were preset to begin recording on 12 March and also terminate 14-days later. Even though the underway periods were only 13-days in length, real world ship schedules are known to change unexpectedly, so having an extra day of recording time provided an opportunity to continue recording should the ship return to port later than originally scheduled. This extra time was not used in the end because the ship returned to port on time after both underways.

2. Psychomotor Vigilance Testing

Nine PVT laptops were positioned throughout the ship to collect attention and vigilance data. Study participants participated in a three-minute PVT to assess their individual level of attentiveness after a period of sustained activity—standing watch. During the baseline period, participants took the tests after each five-hour watch. During the test period, participants took the test after either their three-hour or four-hour watch, depending on which rotation they were on.

The three-minute PVT consists of a black screen with a red rectangular box in the middle of the laptop screen. At random intervals, between two and ten seconds in length, a series of numbers began counting up in the box starting from zero. Each number represents one millisecond. The objective is for a participant to depress the spacebar on the laptop keyboard as quickly as possible after the numbers begin counting. This reaction time is then used to see how attentive, or vigilant, the individual is after having already stood a watch. Lower RTs indicate the individual is more alert; however, RTs that are too low are recorded as false starts. A RT less than or equal to 100ms would not

be humanly possible; consequently, RTs less than 100ms are recorded as a "coincident false start." While the objective is to achieve lower RTs, there is no gold standard in terms of the "best" score for the PVT. RTs are unique to each individual and the baseline results of each individual are compared against the results for that individual's test period RTs. It is also possible to use all the RTs for a specific group of individuals to see shifts in overall group performance. This would, for instance, show whether or not there were changes in RT based on certain watch standing roles or locations.

3. Surveys

The surveys used in this study were a mix of standardized sleep-related surveys and questionnaires developed specifically for this study. The intent of these surveys was to provide an understanding of each individual's pre-existing sleep habits and patterns that could influence test results. They were also used to collect demographic information on participants and assess individual opinions toward a variety of watch rotations used throughout the U.S. Navy.

The surveys provided a mixture of both within-subject and between-subject factors. Within-subject data was collected using a pre-baseline period survey, post-baseline period survey and post-test period survey. These surveys were designed specifically for this study and were aimed at collecting data about the various watch rotations. The between-subject data was collected using the pre-established sleep related surveys.

D. PROCEDURES

In conducting all the analysis for this thesis, an $\alpha = 0.1$ was used for the significance level. The decision to use a lower significance level was made based on the low number of participants, or data points, available in the analysis. Also, the fact that this data was collected on human subjects in a real world operational environment; it was deemed reasonable to lower the significance to 0.1 instead of 0.05.

1. Survey Data

Several different surveys were utilized throughout this study to assess various aspects of each participant's predisposition to sleep-related issues, personal feelings toward various watch rotations, and subjective assessments of sleepiness. Table 2 lists the various surveys used, when they were administered, the purpose of the survey and the appendix in which they can be found. All 32 of the final participants completed each of the surveys.

Survey Name	Underway Period Survey Was Administered	Purpose of Survey	Appendix
Baseline Pre-Underway Participant Survey	Baseline	To collect demographic data; determine participants underway watch station and rotation; watch rotations participant has previously stood; amount of rest/time-off expected given current rotation; to gather open-ended answers regarding watch rotations	B
Baseline Post-Underway Participant Survey	Baseline	To determine subjective feelings about the amount of sleep received using traditional watch rotation; whether or not participants liked traditional rotation	C
Test Post-Underway Participant Survey	Test	To determine how participants felt about alternative watch compared to traditional; whether participants preferred the alternative watch; amount of rest received using alternative watch compared to traditional; open-ended answers regarding alternative watch	D
Pittsburg Sleep Quality Index	Baseline	To determine the participants pre-underway sleep quality	E
Epworth Sleep Scale	Baseline	To determine the participants pre-disposition to sleepiness in various situations	F
Stanford Sleepiness Scale	Baseline and Test	To determine the individuals subjective assessment of their level of sleepiness immediately prior to and leaving their watch station	G

Table 3. Surveys used in the Study

a. Closed-ended Questions

The surveys contained various closed-ended questions, which took the form of Likert scale questions, four-point bipolar scales, and five-point bipolar scales. They were used to assess individual attitudes toward the various watch rotations, the amount of sleep participants expected themselves and others to receive using the various schedules, their individual sleep habits, and their pre- and post-watch sleepiness assessments.

There were also several partially closed-ended questions providing a set of pre-defined response options to respondents while still allowing the flexibility to provide additional information as they felt necessary. These questions were mainly used in questions comparing the proposed alternative watch schedules to various "traditional" watch rotations. Respondents were asked whether or not they felt the alternative schedules are better, same or worse than a specific traditional watch. These questions also allowed respondents to say they had "no opinion" or had never worked the indicated watch. Other partially closed questions allowed respondents to answer "yes" or "no" to a question, then provide amplifying information if "no" was selected.

b. Open-ended Questions

Open-ended questions were designed to allow participants to make comments about their likes and dislikes of the various watch schedules. Each of the tailored questionnaires contained a question allowing respondents to list three things they liked and disliked about the various traditional and alternative watch rotations. There was also a question on the Test Post-Underway Participant Survey allowing participants to write in any number of challenges or issues they had in adjusting to the alternative watch rotations. The total number of open-ended questions was limited to ensure the responses to these questions were meaningful and to ensure that the participants would be inclined to complete them.

2. Sleep Data

The sleep data collected in this study were collected using both objective and subjective methods. Both types of data were collected to determine both how the

individual assessed themselves in relation to sleep, but also how they actually performed in terms of sleep quality and effectiveness. Collecting both types of data allowed for a comparison of one set against the other to see how subjective assessments compare to objective sleep.

a. Actigraphy

The WAMs that participants wore during both the baseline and test periods provided actigraphy data on each participant. This information was downloaded into the Fatigue Avoidance Scheduling Tool (FAST) program where it was further analyzed. FAST calculated the individual predicted effectiveness (PE) for each individual at all points of the study. It also reported the average PE for each individual over the entire span of each underway period. This data was used to compare the amount of actual sleep and the work/rest patterns of each participant between the baseline and test periods. Analyzing the data in this manner allowed for a comparison of major changes in work/rest patterns that resulted from the two watch schedules.

The data sets for actigraphy were unfortunately not complete for all participants. Everyone was issued a WAM at the beginning of each underway period, however, several of the participants experienced malfunctioning or broken watches that failed to record data. Other participants simply failed to wear the watches consistently enough to gather useful data. While small gaps in the data are acceptable—for activities such as showering, exercising, etc.—large gaps in the data of more than a couple of hours begin to significantly impact the overall quality of data. These gaps are viewed in the FAST algorithms as unknown periods of activity, which drives down the PE of the individual. This negatively impacts the overall average PE and can lead to skewing of the data. In order to minimize skewing, this data was ultimately not used in calculating the overall amount of sleep and the effectiveness of the participants. As a result of these data collection issues, only 25 study participants had sleep actigraphy data that could be used.

b. Sleep Logs

Each participant was supplied with a paper activity log during both the baseline and test underways. Each log consisted of two pages, front and back, and was

divided into 15-minute intervals covering a span of 24 hours for each day. Participants were asked to fill in each 15-minute block of log based on the activities they completed during that time period. This subjective sleep data collection method was used to help correlate the actigraphy data to actual operations, which allowed for a comparison of the amount of time participants spent doing various activities. Data gap issues were also present in sleep log data. Several participants failed to complete any sleep logs and some turned in only partial logs. While the lack of sleep logs does not have as significant of an impact as gaps in actigraphy data, incomplete log information made it difficult to verify everyone's sleep data.

3. Psychomotor Vigilance Test (PVT)

The PVT data collected by each laptop provided a single data point for each test participant each time the test was completed. Each data point contained a wide range of pre-established PVT metrics. These metrics include mean reaction time (Mean RT), number of valid responses, standard deviation of RT, minimum RT, maximum RT, mean fastest RT, mean slowest RT, number of errors, number of false starts, and 1/RT, along with various other transformations and reciprocal transformations. Having a test point for each participant during both underway periods allowed for a direct comparison of the PVT results of each individual to see how PVT performance changed using the alternative watches. Because a direct comparison between the baseline and test period was required, several of the participants were removed from the final data set because of inconsistent data. While these participants may have completed the survey or actigraphy portions of the study, they failed to complete PVTs as required and there was no data for them during either the baseline or test period. As a result, only 22 participants had PVT data that could be used for comparison purposes.

IV. RESULTS

A. SURVEY RESULTS

1. Baseline Pre-Underway Participant Survey

The Baseline Pre-Underway Participant Survey was designed to determine the experience level of test participants with regard to years of sea time, watches they have experienced in the past and the different watch locations they have stood. It was also designed to gauge how participants felt about their existing traditional watch rotations and how much rest they did/did not expect to receive while underway during the baseline period. Since all participants had been at sea for at least six months or more, all had some experience with watch standing in one location or another onboard the ship.

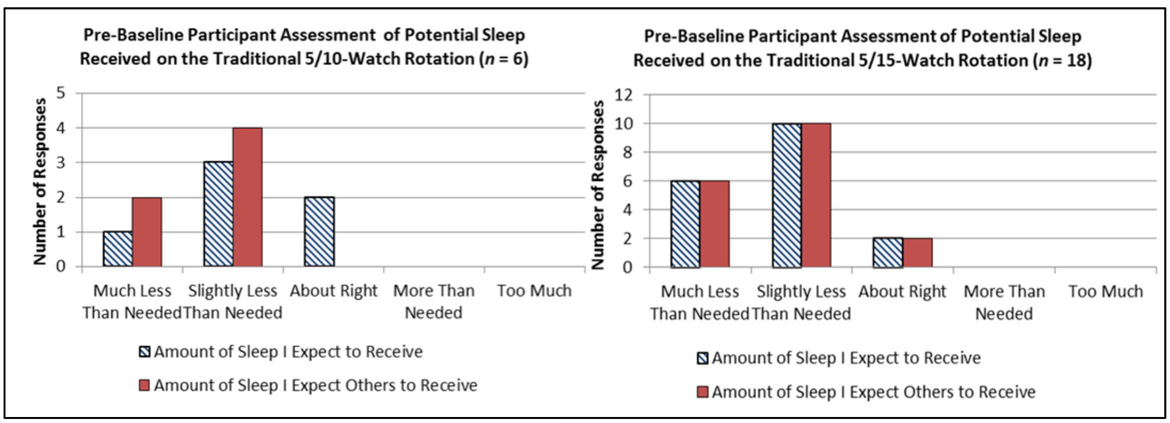

Figure 9. Pre-Baseline Participant Assessment of Potential Sleep

Early on, it was important to determine how much sleep the participants believed they would be getting. This would provide a basis upon which to determine any changes in perceived rest as a result of the alternative watch rotations. Figure 9 shows the results of the Baseline Pre-Underway Participant Survey question numbers eight and nine, which directly asked each individual about the amount of “rest/off-time you anticipate receiving, using your planned watch rotation, during this underway” and the amount of “rest/off-time you anticipate other sailors, standing a watch rotation different than your

own, will receive during this underway." This information could be used to help determine crew preferences to the watch schedules.

Aside from being able to determine changes in anticipated sleep, it was important to be able to determine perceived changes in performance. In order to accomplish this, participants were asked prior to the baseline period whether or not they believed they would have time to develop adequate situational awareness (SA) prior to assuming their watch. SA is a difficult concept to define, but for the purposes of this thesis it is meant as the perception of the operating environment with respect to time and physical space, the understanding of the variables within the space and their projected change over time. Figure 10 shows the results of this question. While the majority of the participants seemed to feel they would have time to develop adequate SA prior to watch, two of the eighteen 3/9 watchstanders and one of the six 4/8 watchstanders indicated concern over their ability to develop adequate SA.

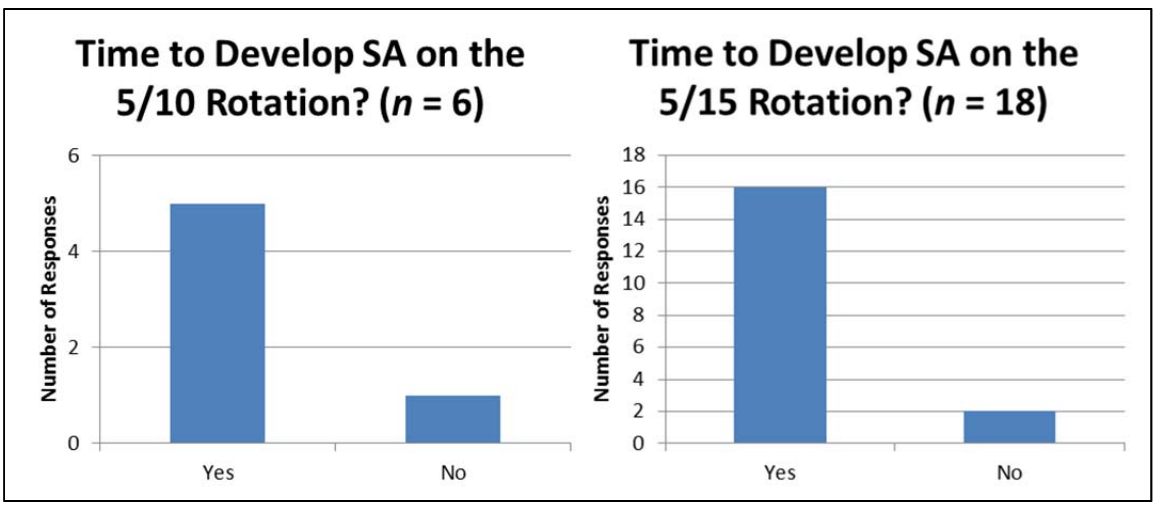

Figure 10. Pre-Baseline Expectation of Ability to Develop Situational Awareness Prior to Assuming the Watch

While this study was not specifically designed or setup to analyze the actual SA of watchstanders, having an understanding of personnel perceptions about their SA will help to identify possible improvements in schedules.

2. Baseline Post-Underway Participant Survey

After completion of the baseline period, participants completed the Baseline Post-Underway Participant Survey asking the same questions asked in the pre-underway survey from the perspective of having actually done them. This was done to contrast what participants anticipated experiencing versus what they actually experienced. There was a significant shift in opinions from participants with regard to the amount of sleep they received, as seen in Figure 11. In Figure 9, most participants expected to receive "slightly less sleep than needed." In Figure 11, responses were more spread out in terms of the amount of sleep they felt they received.

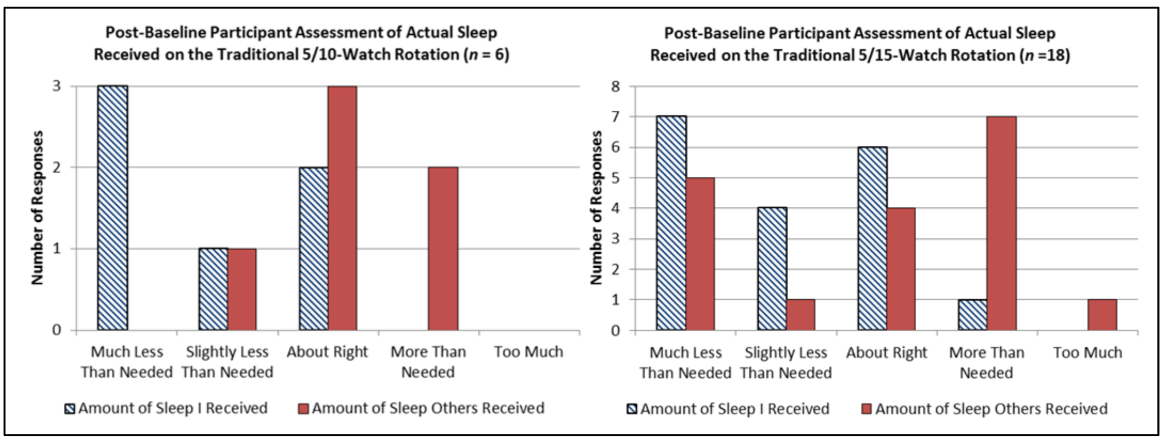

Figure 11. Post-Baseline Participant Assessment of Actual Sleep Received

The more interesting difference here is the significant shift in perception of the amount of sleep others received, relative to the study participants. This indicates that the study participants felt other, non-participants, received not only more sleep than initially expected, but also more than the study participants themselves.

There was also a shift in terms of respondent assessments of their ability to develop SA. It is seen in Figure 12 that the majority of four-section watch personnel still believed they were able to develop SA prior to watch, but only half of those on the three-section watch held that belief.

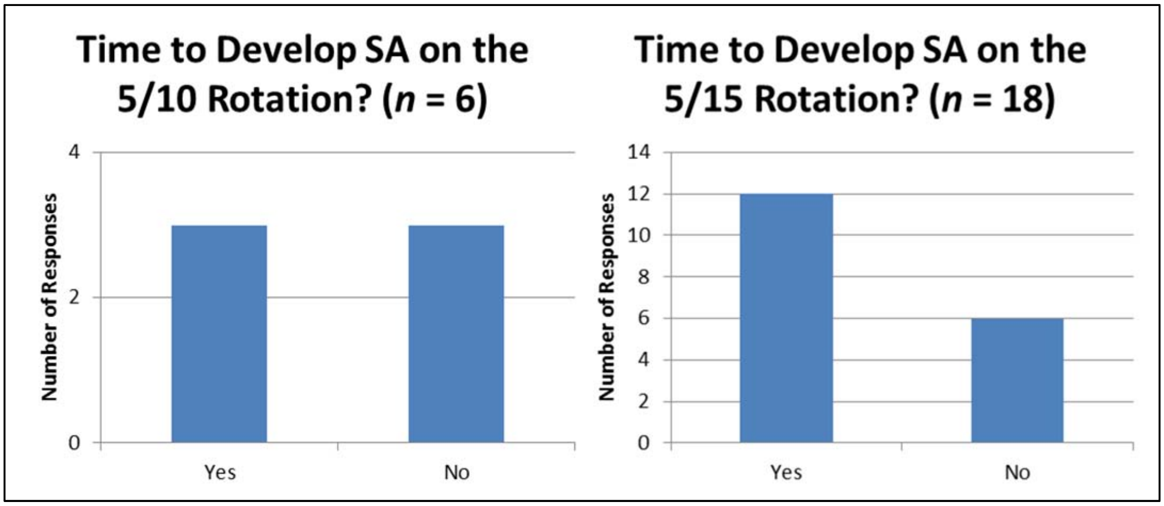

Figure 12. Post-Baseline Assessment of Ability to Develop SA Prior to Assuming the Watch

Determining the significance of the change in responses was difficult given the low number of respondents. McNemar's Chi-squared test for symmetry was conducted to determine if the change in responses was actually significant. This test compared the number of respondents in both the "Yes" and "No" categories from the pre-baseline to the post-baseline period and tabulates the outcomes of the two tests based on the sample size. The null hypothesis for this test assumes that the marginal probabilities for each outcome remain the same for both surveys. Table 4 shows the results of this test.

Watch Rotation	X^2 Value	p-value
5/15	2.25	0.1336
5/10	0.5	0.4795

Table 4. McNemar's Chi-squared Test Results Comparing Pre-Baseline and Post-Baseline Survey Results for Situational Awareness

These results show there is not enough significance to reject the null hypothesis for either the 5/15 or 5/10-watch rotations. This indicates that the marginal proportions are not significantly different from one another.

3. Test Period Post-Underway Participant Survey

At the completion of the underway test period participants completed the Test Period Post-Underway Participant Survey to ask questions regarding participant opinions of the 3/9 and 4/8 watch rotations compared to the traditional watches experienced during the baseline period. The survey also asked the same questions regarding respondent assessments of the amount of sleep they received relative to how much others received during the test period. Figure 13 shows these results. Overall respondents felt that nearly everyone, both study participants and non-participants, received about the right amount of sleep during the underway.

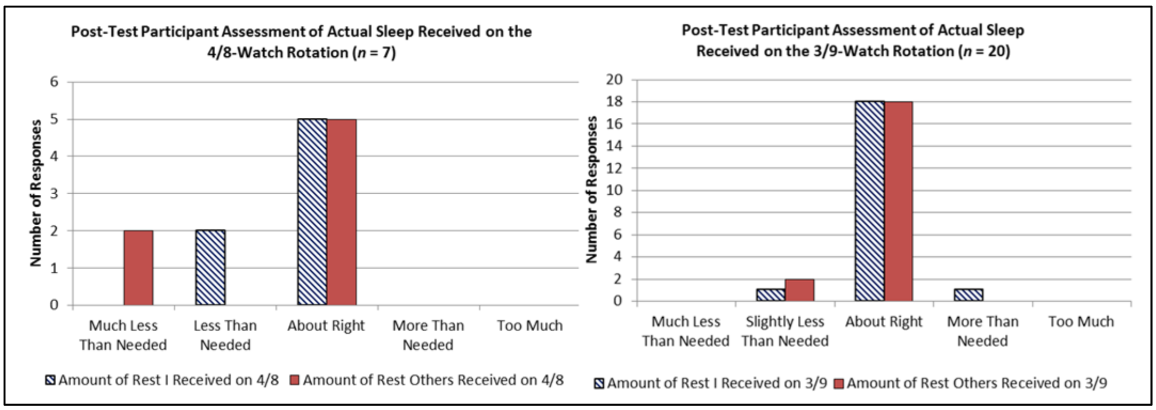

Figure 13. Post-Test Participant Assessment of Actual Sleep Received on the 3/9 and 4/8-Watch Rotations

Another change was the shift in assessment regarding SA development when using the alternative watch rotations, as seen in Figure 14. Only one individual felt there was not adequate time to develop SA prior to watch on the 3/9, a decrease from the baseline period. Again, the McNemar test was used to compare this post-test period question regarding SA to the same question from the post-baseline period in Figure 12. Table 5 shows the results of these comparisons.

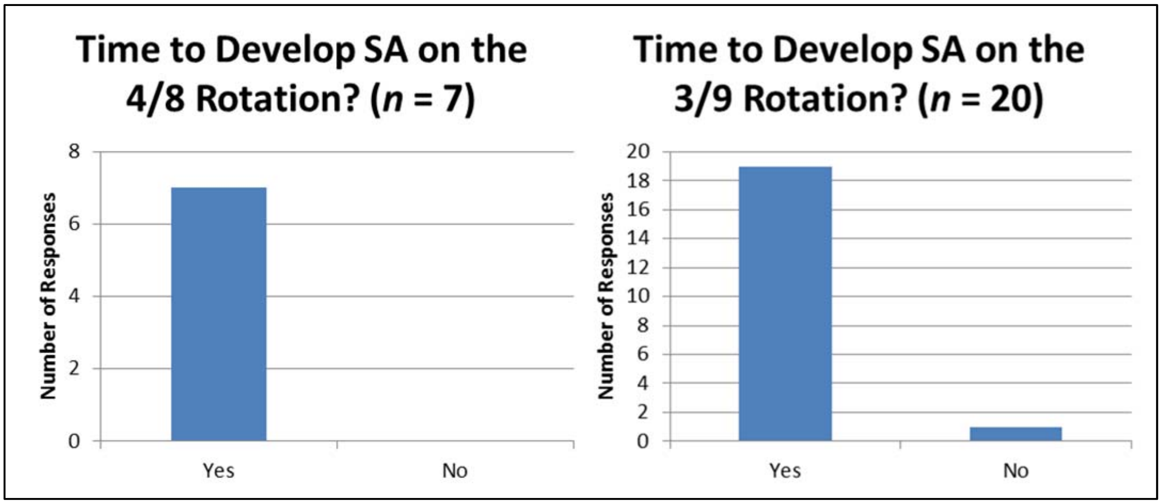

Figure 14. Post-Test Period Assessment of Ability to Develop SA Prior to Assuming the Watch

Watch Rotation	X^2 Value	p-value
3/9	3.2	0.0736
4/8	1.33	0.2482

Table 5. McNemar's Chi-squared Test Results Comparing Post-Baseline and Post-Test Period Survey Results for Situational Awareness

The McNemar test did show a significant change in opinions regarding the development of SA between the 5/15 and alternative 3/9-rotation. A p-value of 0.0736 for the 3/9-rotation may not be as strong as the 0.05 desired, but it met the significance level previously established for this thesis and indicates there is a significant difference between opinions. Further research with a larger sample size is needed to more definitively assess whether or not this change in opinions is translatable to a larger population.

A number of questions were directed at determining viewpoints on the 3/9 and 4/8 watch in comparison to other traditional Navy watch schedules. The results of these comparisons can be seen in Figure 15, which compares the 3/9-watch rotation to the traditional 5/15 and the 4/8 to the traditional 5/10-watch rotation. In general, participants felt the 3/9-rotation was not only equal to the 5/15-rotation, but better.

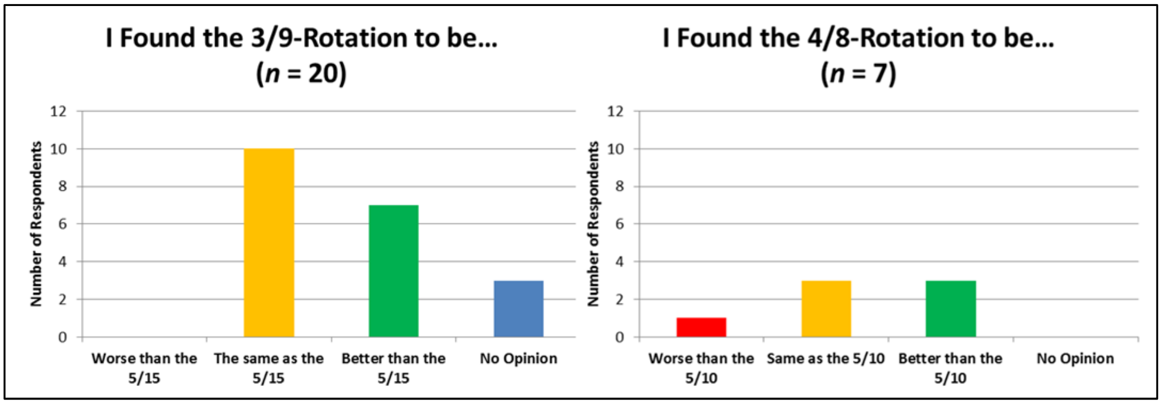

Figure 15. Survey Results Comparing Opinions of Alternative Watch Rotations to Traditional Rotations

The participants felt about the same with regard to the 4/8-rotation. One respondent did feel it was worse than the traditional 5/10-rotation, but most felt it was the same or better. Even though the total number of respondents to this question (n = 7) was relatively small, these respondents were the entire population of participants on the alternative 4/8-watch. The 4/8 was also compared to the 6/12-rotation, another alternative to the three-section watch rotation. These results, as seen in Figure 16, were almost identical to those regarding the 5/10. Overall, the 4/8-rotation was viewed to be about the same as other traditional three-section rotations.

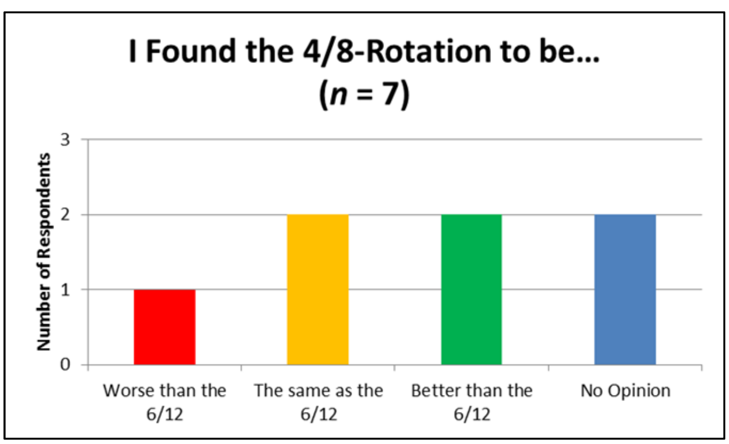

Figure 16. Survey Results Comparing Opinions of the 4/8-Watch Rotation to a Traditional 6/12-Watch Rotation

B. ACTIGRAPHY RESULTS

One of the major objectives of this study was to assess whether there was a difference in the actual amount of sleep personnel received between the baseline and test periods. If such a difference exists, it would help to either support or refute the assertions that the alternative watch rotations offer value in terms of increasing watchstanders' sleep. During the course of the study, several participants had incomplete actigraphy data as a result of data corruption and malfunctions in the wrist activity monitors (WAMs). As a result, there was an incomplete amount of actigraphy data on nine participants and these participants were dropped from the final analysis. Of the remaining participants who had actigraphy data and started on the 5/15-rotation, four of them were shifted to the alternative 4/8 instead of the 3/9-rotation. This shift in rotations was a result of the JASON DUNHAM's underway operations and it did not facilitate the comparison of the traditional four-section watch with the alternative four-section watch. As a result these participants had to be dropped from the final analysis. Dropping these personnel led to only 11 personnel having the required data under the required conditions for analysis of the 3/9-rotation.

The actigraphy data collected provided both the average amount of sleep and average predicted effectiveness (PE) for each participant per day. Figure 17 shows the average number of hours of sleep per day each crewmember received during the baseline period. It was also possible to see the average amount of sleep per sleep interval. Anchoring the amount of sleep of an individual on a 24-hour "day" is an arbitrary reference that may not be the most accurate method of examining sleep for individuals. Since sleep intervals often overlap days, looking at the amount of sleep received during each sleep interval may give a better idea of the actual amount of sleep received. The average amount of sleep received during each sleep interval on the baseline is seen in Figure 18.

Figure 17 shows that eight out of the eleven participants received fewer than six hours of sleep. Only one person was actually able to average more than 7 hours of sleep,

which is well below the recommended sleep amount for adults (National Sleep Foundation, 2011). The average amount of sleep for all 5/15 watchstanders was 5.56 (±0.788) hours of sleep.

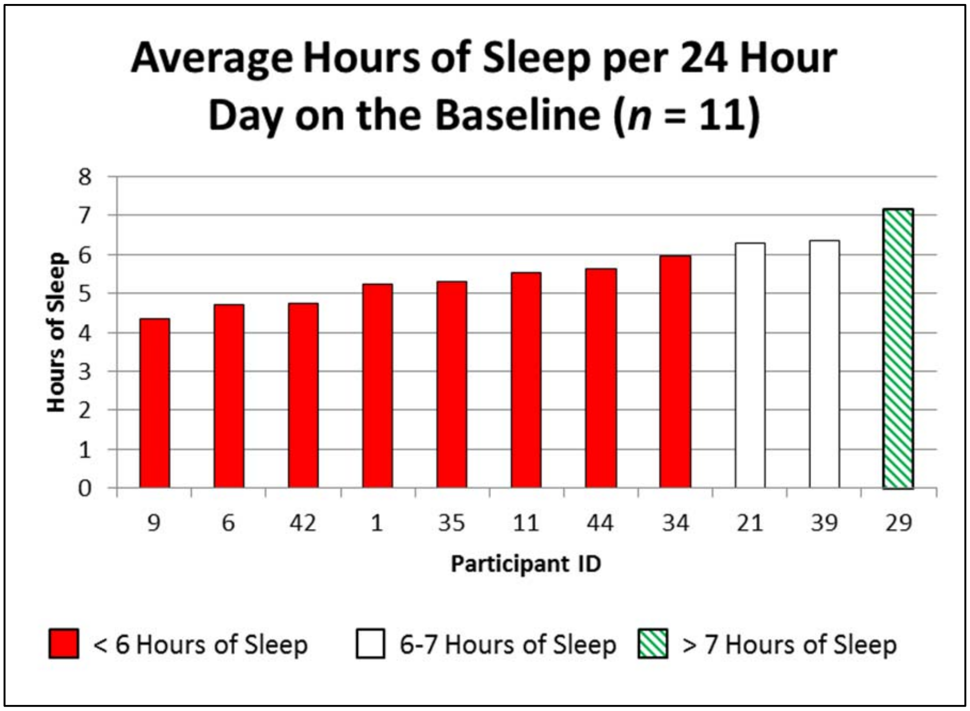

Figure 17. Average Hours of Sleep per 24 Hour Day on the Baseline

Figure 18 shows a different picture of how much sleep personnel received. It shows that all personnel, on average, received less than six hours of sleep per sleep interval. This means that each time personnel slept, they slept for fewer than six hours. The average amount of sleep per interval for all participants was 4.71 (±0.578) hours.

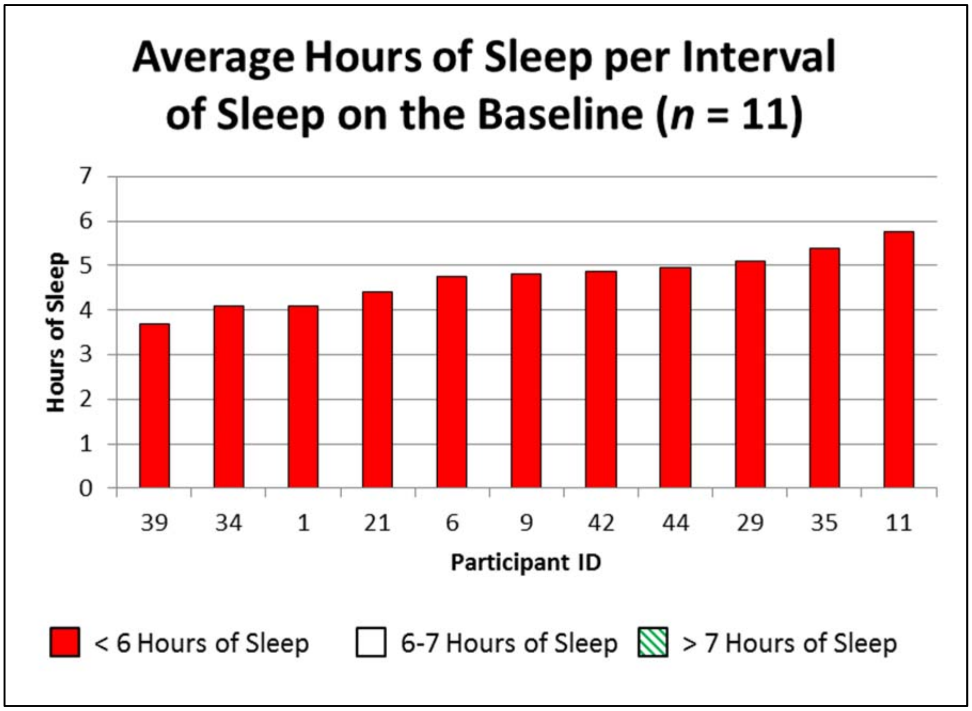

Figure 18. Average Hours of Sleep per Interval of Sleep on the Baseline

Figure 19 shows the average amount of sleep received per day on the test period. Here it is seen that personnel received only slightly more sleep per day. Here two personnel were consistently receiving more than seven hours of sleep per day and two personnel were receiving more than six hours of sleep. During the test period, the average amount of sleep per day was 6.11 (±0.852) hours.

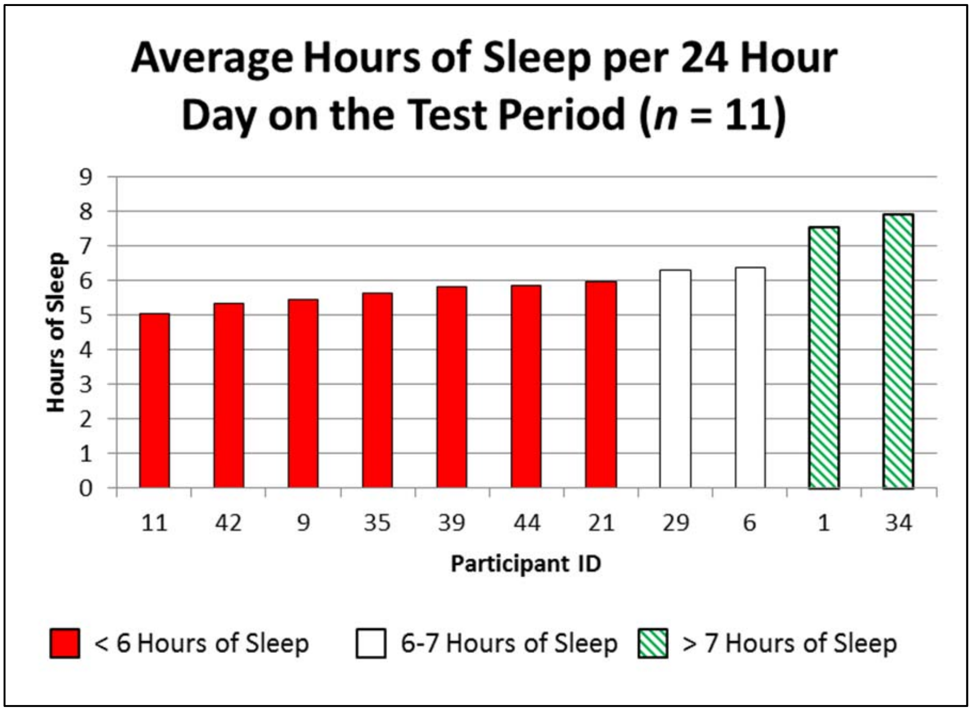

Figure 19. Average Hours of Sleep per 24 Hours Day on the Test Period

A similar change in the amount of sleep received per interval was expected during the test period; however, Figure 20 shows that personnel still received an average of less than six hours of sleep per sleep interval. The actual average amount of sleep per interval was 4.55 (±1.013) hours. This was not a significant difference from the amount of sleep per interval on the baseline.

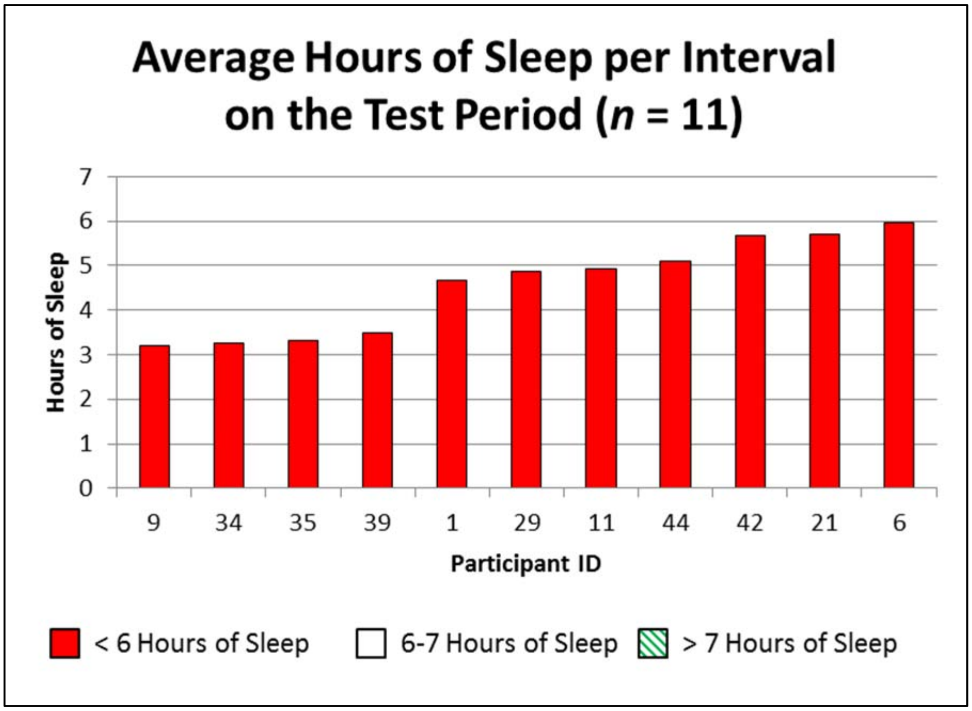

Figure 20. Average Hours of Sleep per Interval of Sleep on the Test Period

It is important, though, to look not only at the total amount of sleep gained, but to examine the differences in the amount of sleep gained between the two periods. In order to determine change in the amount of sleep for each participant, the difference (Δ_i) between the average minutes of sleep for the test period (μ_{iT}) were subtracted from the average minutes of sleep during the baseline period (μ_{iB}) for each subject using Equation 1.1.

$$\Delta i = \mu iT - \mu iB \tag{1.1}$$

Calculating the differences in average actigraphic sleep shows whether participants experienced more or less sleep. If the Δ_i for participant i is positive, the average amount of sleep received on the test period is greater than the average amount of sleep received during the baseline. Results of these calculations can be seen in Figure 21. While the overall average sleep results from Figures 19 through 22 do not depict a clear improvement in participant sleep, Figure 21 shows that seven of the eleven, or 63.6% of

the 3/9-watchstanders, received more sleep. Despite the fact that not every participant received more than six hours of sleep, showing that personnel are able to receive any amount of extra sleep is favorable.

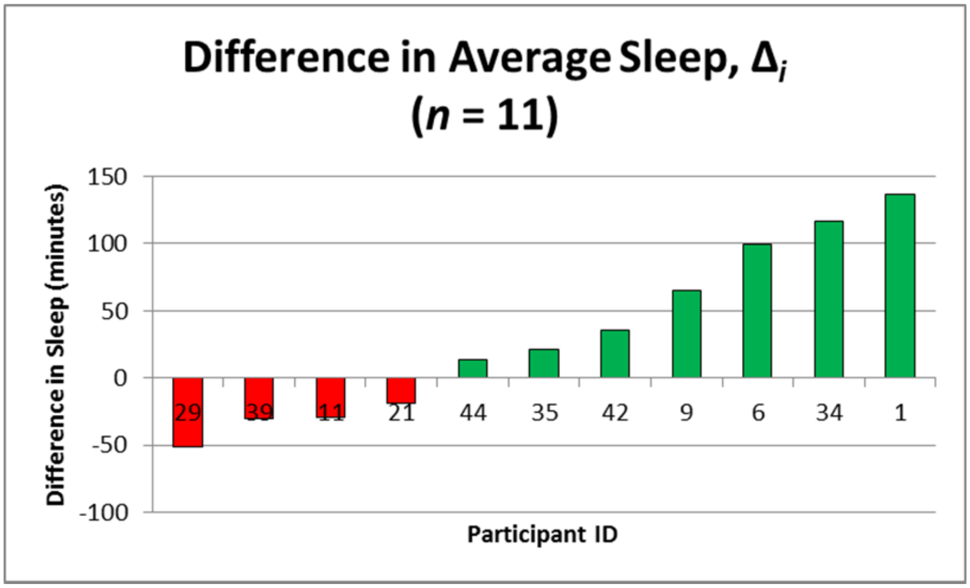

Figure 21. Difference in the Average Minutes of Sleep from Baseline to Test Period

To confirm whether or not there was an actual difference in the amount of sleep received, paired t-tests were performed between the average sleep for each participant on the test period (μ_{iT}) and the baseline (μ_{iB}). The null hypothesis assumed the amount of sleep received on the baseline was less than the amount of sleep received on the test period. For all of the analysis performed on this data, a significance level of 0.1 was used instead of 0.05. The decision to use a higher significance level was based on the low number of total participants (n = 11) and the fact that this was human research conducted in a real-world operational environment.

Table 4 contains the summary information for the paired t-tests comparing the average amount of sleep during the baseline and test periods. The results of the t-test show that there was a significant difference in the amount of sleep received per day on the 5/15 and the 3/9-rotation. The results also show no difference in the amount of sleep

per sleep interval. This indicates that personnel received about the same amount of sleep each time they slept on both the baseline and test period.

Sleep Compared	t-value	p-value	Df
Per Day	1.678	0.0622	10
Per Interval	0.4807	0.6794	10

Table 6. Results of Paired t-test for Actigraphy Data

The amount of sleep is, however, not the whole picture. Timing and quality of sleep are also important considerations for watchstander performance. A different view of improvement is the change in PE for individuals, seen in Figure 22. Calculating the difference in PE was done in the same manner as calculating the difference in sleep. This figure shows that nearly all participants had a higher PE despite having lower sleep amounts. On average the personnel on the 5/15 had a 78.72% (±9.717) PE, while personnel on the 3/9 had an average PE of 83.48% (±2.496).

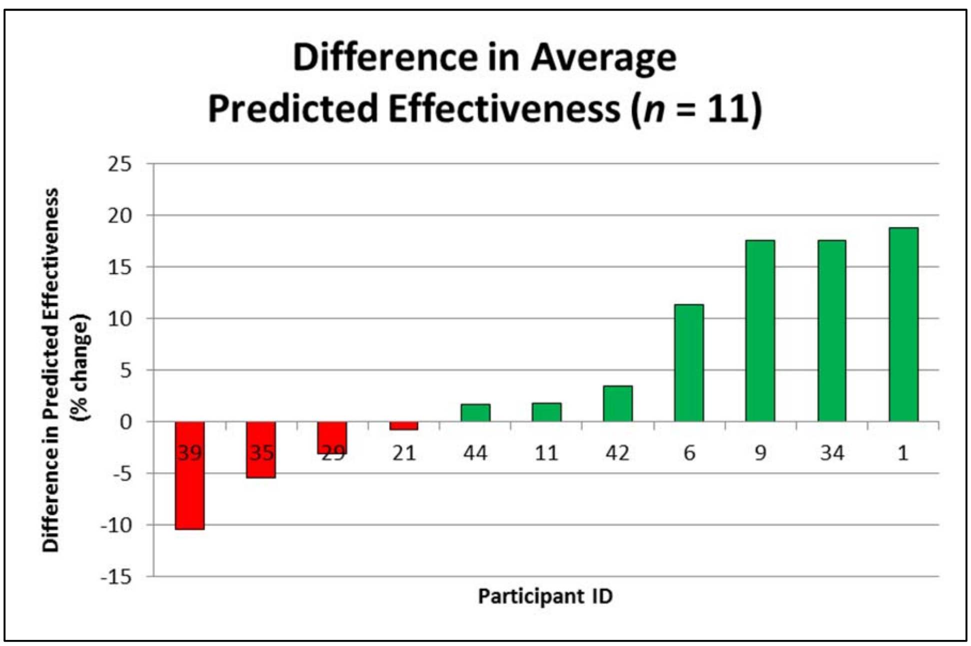

Figure 22. Difference in Average PE from Baseline to Test Period

Another paired t-test was used to confirm whether or not there was an actual difference in PE between the 5/15 and 3/9. Again, the null hypothesis assumed that there was no difference in the PEs, but the null was rejected (p-value = 0.0742) indicating that personnel did have, on average, a higher level of PE on the 3/9.

Figure 23 shows a plot of the difference in average sleep against the difference in PE, for each individual, between the two underways. It shows there is a fairly strong correspondence in the individuals who experienced more sleep and higher PE values. A linear regression line, plotted over the data points, shows that as the difference in sleep grows larger, the average PE also grows. The R^2 value for this regression was 76.12%, which again indicates a strong relationship between these values.

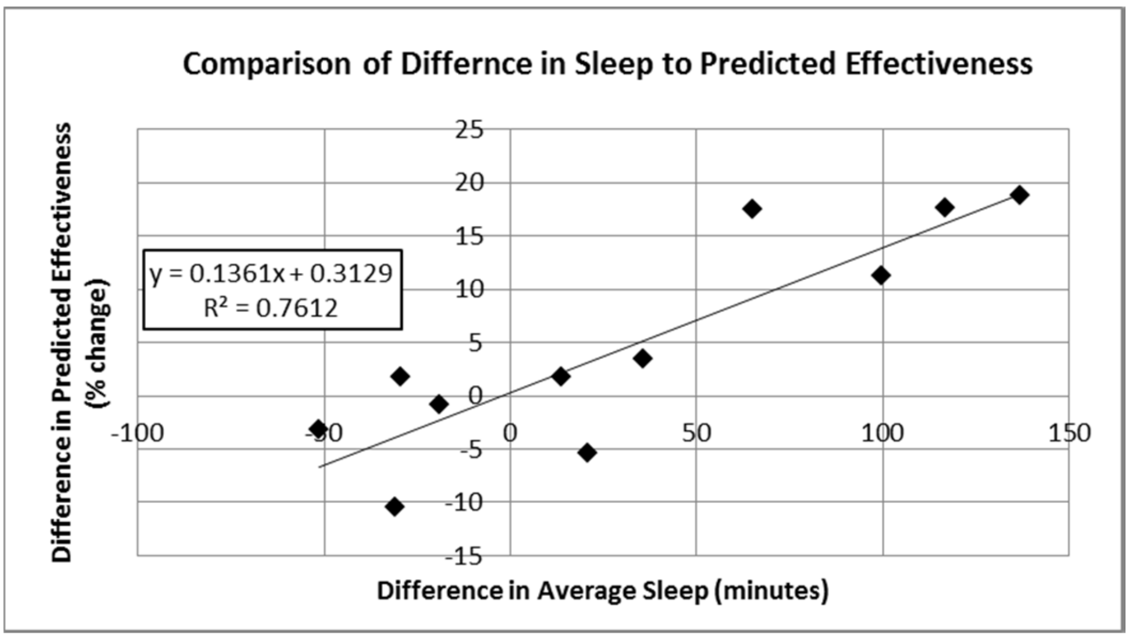

Figure 23. Comparison of Difference in Average Amount of Sleep to Difference in Predicted Effectiveness

Quality of sleep is also a critical component in performance. It was hypothesized that the 3/9-rotation would provide an opportunity for better quality of sleep based on the sleep cycles of each individual. A shift in the sleep cycles of individuals was noted in their actograms. One example of this can be seen for Participant 11 in Figure 24. Looking at the difference in the amount of sleep received (Figure 19) implies the alternative

rotation was of no benefit because this participant received less sleep on the 3/9. When you look at the change in PE (Figure 20), however, this individual had a higher overall PE. This change in PE resulted from the more consistent sleep pattern seen in Figure 24. The black marks in this figure show the amount of motion each individual experienced. The more motion recorded, the higher the black marks are for each one minute interval. Periods of sleep are indicated based on the color coding seen in Figure 24. It can be seen in these intervals that there is a significant reduction in participant motion. Other periods of time when the WAMs did not record data are marked as "off wrist" times and are also indicated by the color coding in Figure 24.

In Figure 24, it can be seen that Participant 11 experienced more consistent periods of continuous sleep during the test period as compared to the baseline period where shifting periods of varying length sleep were experienced. Despite receiving an average of 29.26 minutes less sleep per day during the test period, Participant 11 experienced a 1.73% increase in average PE as a direct result of a more consistent sleep pattern. This change does not appear to be significant, but any positive change in effectiveness is good. Similar changes in sleep patterns were seen in all the participants with improved PE.

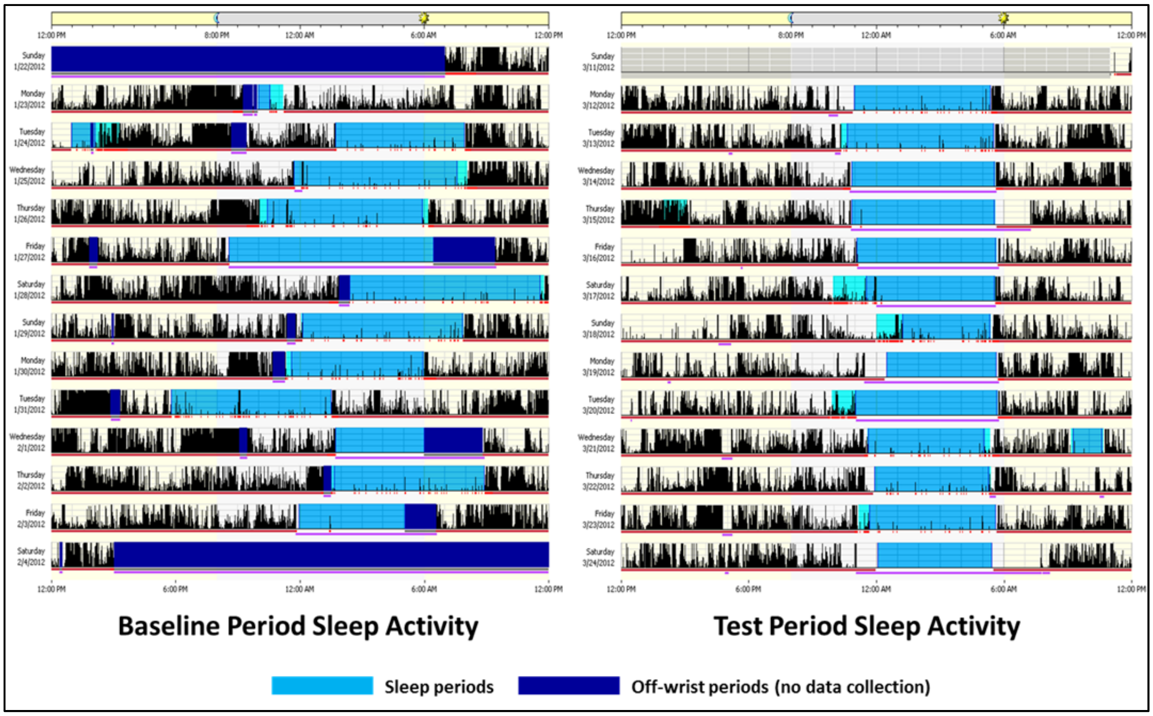

Figure 24. Sleep Activity for the Baseline and Test Periods for Participant 11

Four of the 3/9 participants who experienced a drop in PE—participants 39, 35, 29 and 21—also showed similar sleep pattern changes, as those experienced by Participant 11. Figure 25 shows the actograms for Participant 29 during the baseline and test periods. These changes appear to be similar to the other participants between the baseline and test period, so it is not clear exactly why these two individuals had a lower calculated PE.

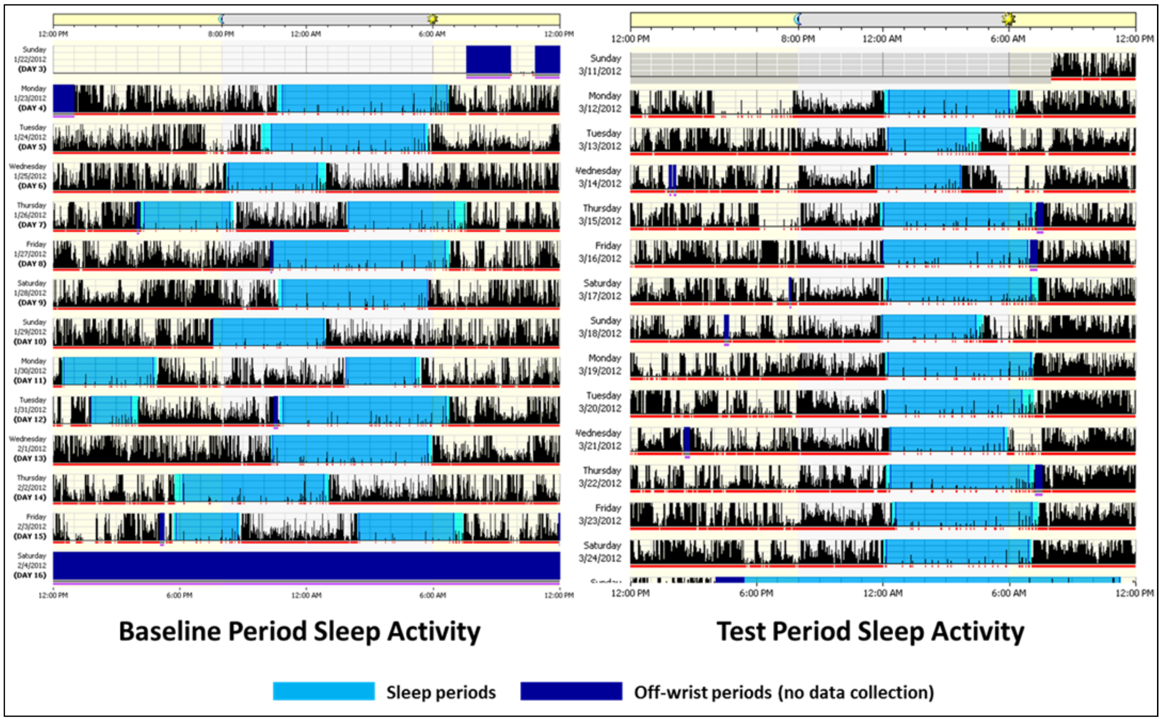

Figure 25. Sleep Activity for the Baseline and Test Periods for Participant 29

Participants also completed sleep logs, in conjunction with the actigraphy data, as a record of their daily activities. This self-reported information was used primarily to verify the sleep and work periods of the actigraphy data. The WAMs may record 15-minute periods as "sleep" due to a low activity count for the participant even though the participant was not actually sleeping during that time. These minor discrepancies can skew the sleep data once it is imported into the Fatigue Avoidance Scheduling Tool (FAST), which will result in inaccurate sleep and PE data. The sleep logs were compared against the actigraphy data in order to correct the incongruities seen in the actigraphy data. Doing this ensured the FAST results were as accurate as possible.

As a result of examining the sleep logs, it was also discovered that participants self-reported sleeping an average of 7.1 hours during the baseline period and only 6.4 hours during the test period. These self-reported sleep periods, however, are not entirely accurate. As previously discussed, the majority of participants received less than seven hours of sleep during the baseline, therefore it is not possible for the average to be 7.1 hours. The average daily sleep, according to the WAMs was actually 5.56 hours of

sleep during the baseline and 6.11 hours during the test period. While the sleep logs provide a great deal of insight into the daily activities of the individuals, the data collected from it must be analyzed carefully to ensure results are not skewed by self-reporting.

C. PSYCHOMOTOR VIGILANCE TESTING RESULTS

The literature previously reviewed in this thesis shows that sleep deprivation can have a large impact on individual performance. Assessing the performance of watchstanders, however, goes beyond looking solely at the amount of sleep personnel receive. Another goal of this study was to determine actual changes in performance. While PE data generated by FAST from actigraphy data provides insight into performance, this information is computed from previously established and validated algorithms as a prediction of performance. Gauging actual performance is more difficult, especially in the operational environment. The simple reaction time test provided by the psychomotor vigilance test (PVT) was previously shown in the literature review to be a proven metric used to assess that performance.

For this data analysis, only 15 participants had data that could be analyzed. Several of the participants failed to complete PVTs during the test period, so there was no means of comparing their 5/15 performance with their 3/9 performance.

For this thesis, the primary PVT metric used to describe PVT performance was the mean reaction time (Mean RT) of the individual taking the test. The Mean RT is a simple metric that measures how fast personnel respond to a stimulus. Since there is no set standard or "best score" for the PVT, results are compared within the individual to determine if there was a change in performance between the baseline and test periods.

This study also examined the standard deviation of reaction times (SDRT) for each participant. When looking at performance of personnel, consistency is a large factor. The SDRT is a measure of how consistently personnel responded to the PVT stimulus. The number of PVT lapses per test were also examined. A "lapse" occurs whenever the

PVT stimulus is presented and the respondent fails to respond within 300 ms. A higher number of lapses may indicate that the individual was either distracted or unaware the stimulus has been presented.

1. Examination of Mean Reaction Time (Mean RT)

The average of all Mean RTs was computed for each individual so a comparison of the average between both underways could be performed. The difference in average PVT Mean RT was taken for each participant using Equation 1.1, where μ_{iT} represents the average of all Mean RTs for individual i during the test period and μ_{iB} represents the average of all Mean RTs for that individual during the baseline period. The Δ_i then represents the difference between the two and the lower the Δ_i, the better. A lower Mean RT is representative of higher alertness because it indicates the individual responded more quickly. Therefore, subtracting the μ_{iB} from μ_{iT} should result in a negative value, which indicates an improvement. These results can be seen in Figure 26.

Figure 26 shows that six participants experienced an improvement in PVT performance, while nine had worse PVT performance on the 3/9-rotation. Looking at the average difference in PVT performance in the individual does not yield convincing support, one way or the other, in terms of using the traditional or alternative watch rotations. A paired t-test comparing these results did not indicate any significant change. It could not be concluded that there was a measureable difference in Mean RTs between the two underway periods.

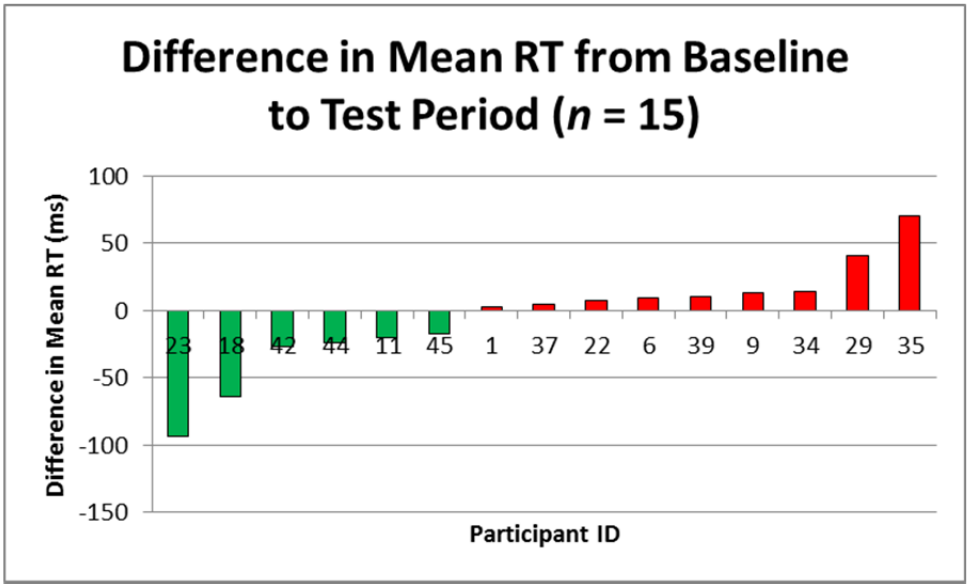

Figure 26. Difference in PVT Mean RT from Baseline to Test Period

When we look at the Mean RTs for all tests over time, however, a different result is seen. Figure 27 shows the Mean RTs plotted over time for both underways. In this figure time is represented by the length of the underway, so time is increasing as the length of the underway increases. In this figure it appears as though the Mean RT for individuals is increasing, or getting worse, as the length of the underway increases. The linear regression line plotted over the data shows this trend visually. The p-value for time as a factor in this regression was 0.0382, which indicates that the day of the underway is a significant factor in explaining how Mean RT increases as time increases. A regression line was also plotted over the test period data, but the p-value for time in this regression was 0.4774, indicating it was not a factor during the test period. Still, no statistically significant difference was noted in the Mean RTs between the baseline and test period.

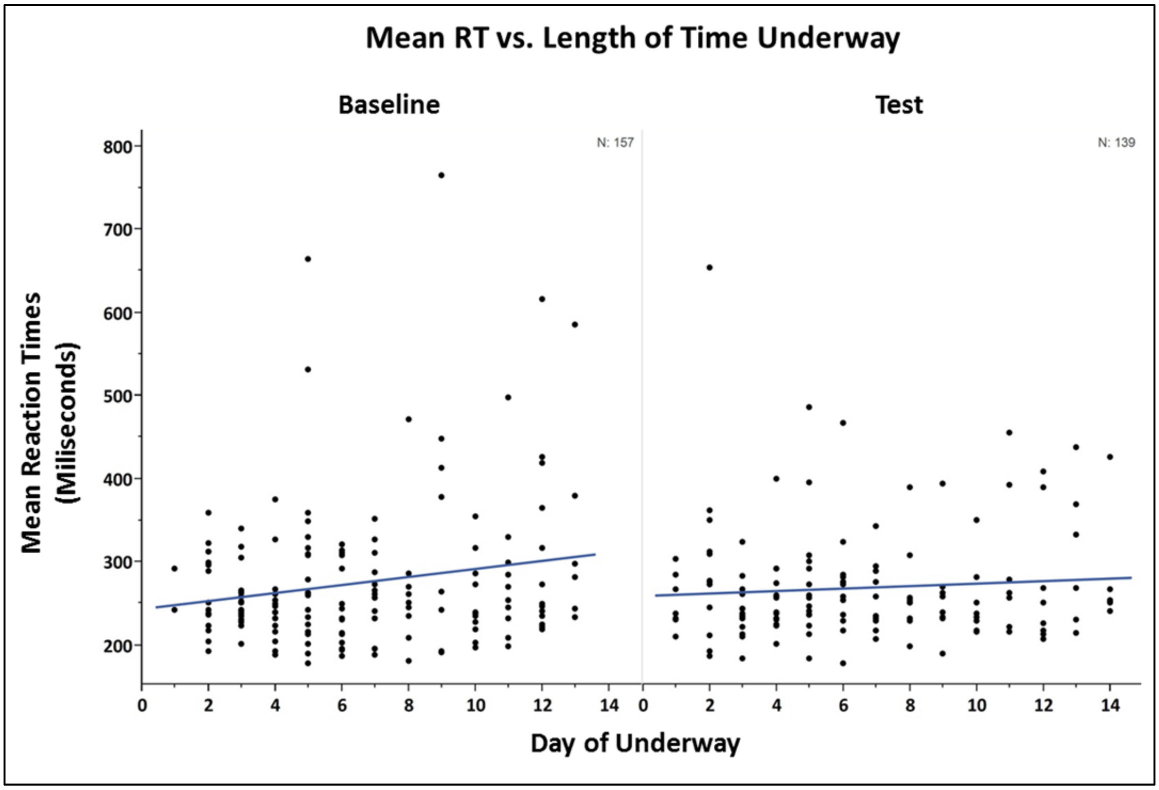

Figure 27. Mean RT vs. Length of Time Underway

An in-depth look at the Mean RT for individuals based on the time they stood watch was also needed to see how personnel performance changed based on the time of day. To facilitate this analysis, each watch rotation period for the baseline and test period was grouped together based on the time of day the watch was stood. These groupings allowed the individual watch periods for the baseline to be compared with corresponding watch intervals on the test period. Table 5 shows how the different watches were grouped together. The groupings were made such that the three hour rotations on the 3/9 could be most directly matched with the same watch time interval from the 5/15-rotation.

Table 5 also shows how many total PVT tests are included in each of the watch intervals for the two underway periods. For the most part, the number of PVT tests is fairly uniform for all watch intervals, except for intervals four and five of the test period. Watch interval four on the test period only has eight tests, while the same interval on the baseline had 34. It is unknown why there is such a difference in the number of tests, but it is probably a result of participants not taking the required PVTs at the end of each watch.

Watch interval five on the test period had 54 total PVT tests, while the same interval on the baseline only had 36. The cause of such a higher number of PVTs on the test period in this interval is because of the decision to combine the 1500–1800 and 1800–2100 watch periods together into one interval. When you break these two watch periods apart, the 1500–1800 had a total of 25 PVTs and the 1800–2100 had 29 PVTs.

"WatchInterval" Code	**1**	**2**	**3**	**4**	**5**
Baseline Period (5/15) Watch Periods	2200-0200	0200-0700	0700-1200	1200-1700	1700-2200
Number of Baseline PVT Tests	30	32	27	34	36
Test Period (3/9) Watch Rotations	2100-0000 0000-0300	0300-0600	0600-0900 0900-1200	1200-1500	1500-1800 1800-2100
Number of Test Period PVT Tests	24	30	33	8	54

Table 7. Watch Rotation Groupings for "WatchInterval" Code

Once the groupings in Table 5 were established, the individual PVT tests were coded with a "WatchInterval" variable based on the time of day the test was taken to match the watch period times in the table. This allowed for a direct comparison of the PVT performance metrics based on the time of day for each underway period. A Welch two-sample t-test was used to compare the means of the Mean RTs between individual watch intervals for both underways. This test assumed the true difference in the means for the Mean RTs of both periods was greater than zero. Table 6 shows how the Mean RTs compared. This table shows that there was a significant change in the Mean RTs for personnel on watch intervals one, three and four. Figure 28 also shows a series of boxplots of the Mean RTs for each watch interval on both the baseline and test period.

Watch Interval	**t-value**	**p-value**	**Degrees of Freedom**	**Baseline Mean**	**Test Mean**
1	1.5901	0.0606*	33.462	304.9677	266.5833
2	-1.0865	0.8592	60.465	324.9091	377.8710
3	1.4179	0.0825*	35.659	316.0	264.0
4	1.6068	0.0581*	39.344	334.6216	266.1250
5	0.4440	0.3295	49.171	287.9189	274.3519

Table 8. Welch Two-Sample t-Test Comparisons of Mean RTs

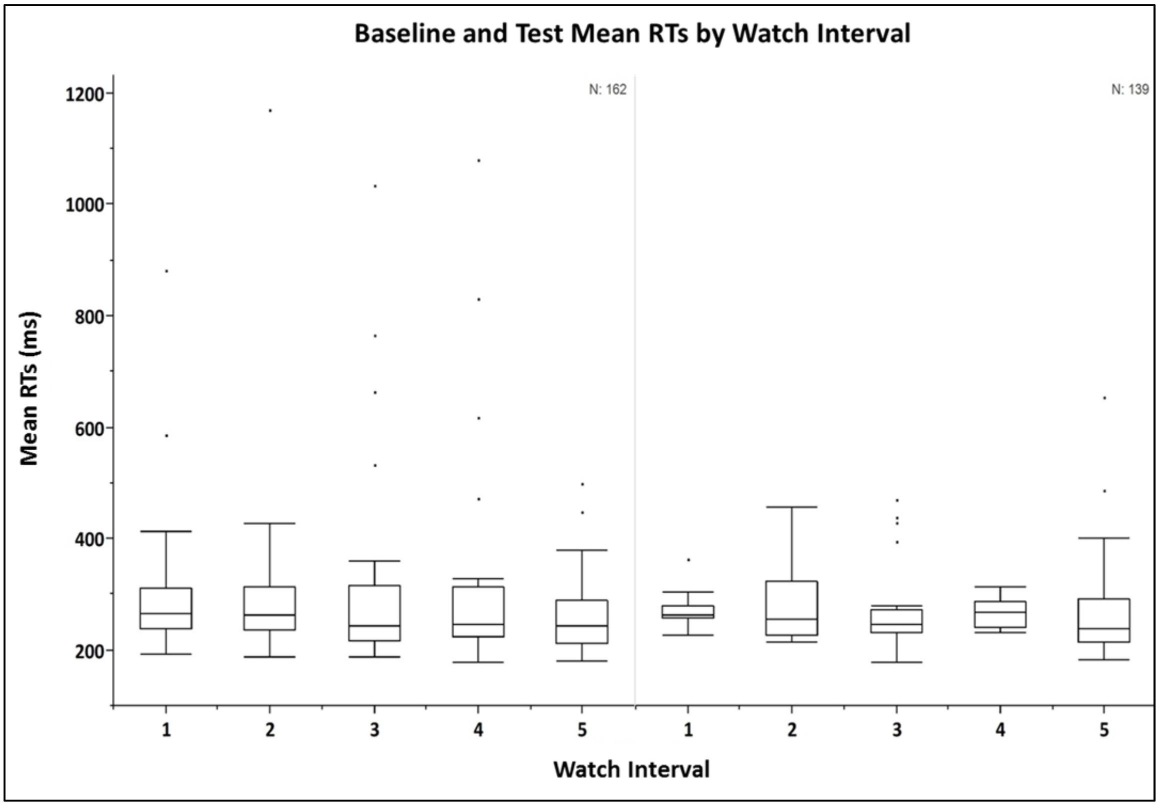

Figure 28. Baseline and Test Mean RTs by Watch Interval

After looking at Figure 28, it appeared that there was a difference in the variation of Mean RTs between the corresponding watch intervals on both periods. In order to determine if such a difference in variation actually existed, an F-test was used to compare the variance between the same watch interval of each underway. Table 7 shows the results of these F-tests. The null hypothesis of the F-test assumed that the ratio of the variances for a specific watch interval on the baseline and the same interval on the test period is equal to one.

Watch Interval	F-value	p-value
1	22.0909	< 0.0001
2	0.8246	0.5918
3	7.8656	< 0.0001
4	87.3991	< 0.0001
5	3.7701	< 0.0001

Table 9. F-test Results Comparing Mean RT Variances between the Baseline and Test Period

It is clear that there was in fact a difference in variance of Mean RTs for all watch intervals, except interval two. This indicates that personnel on the night, day and evening watches had less variation in performance on the 3/9 rotation than the 5/15. Based on these results, it was necessary to look more in-depth at the standard deviations of each PVT test to see how personnel variability changed between each underway.

2. Examination of Standard Deviation of Reaction Time (SDRT)

As previously mentioned, the SDRT may give an indication of the consistency of performance for individuals. The first step in identifying a possible change in the SDRT was to calculate the difference in average SDRT for each individual on both the baseline and test period. This was done using the same method previously identified in equation 1.1, where μ_{iB} represents the average SDRT for participant i on the baseline period and μ_{iT} represents the average SDRT for the same individual during the test period. The Δ_i then represents the difference between the two. Figure 29 shows a plot of the Δ_i for each individual. Since the majority of the participant's Δ_i values fall in the negative range, this indicates that most participants experienced reduced variability in performance on the 3/9-rotation.

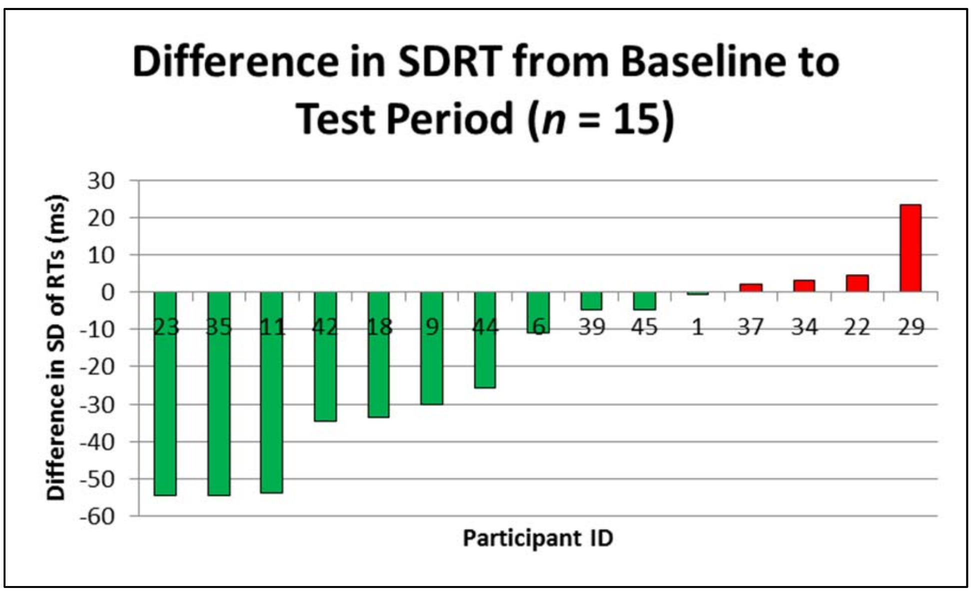

Figure 29. Difference in SDRT from Baseline to Test Period

A paired t-test was conducted to compare these average SDRTs for each individual. The null hypothesis assumed there was no difference in the SDRT for each individual, which was rejected with a p-value = 0.0061. This indicates that there was a significant shift in the SDRT for personnel, which confirms what was seen in Figure 29.

Figure 30 shows the SDRTs for all PVTs plotted over time for both underway periods. A similar trend is seen in Figure 30 as was seen in Figure 27. As time increased, the RTs of individuals became more varied on the baseline. This trend was not seen as strongly on the 3/9-rotation. The linear regression lines plotted over the baseline had a p-value of 0.0382 and the line plotted over the test period had a p-value of 0.4774, which indicates that the increasing length of the underway was not a significant factor in the SDRT of personnel on the 3/9, but it was on the 5/15.

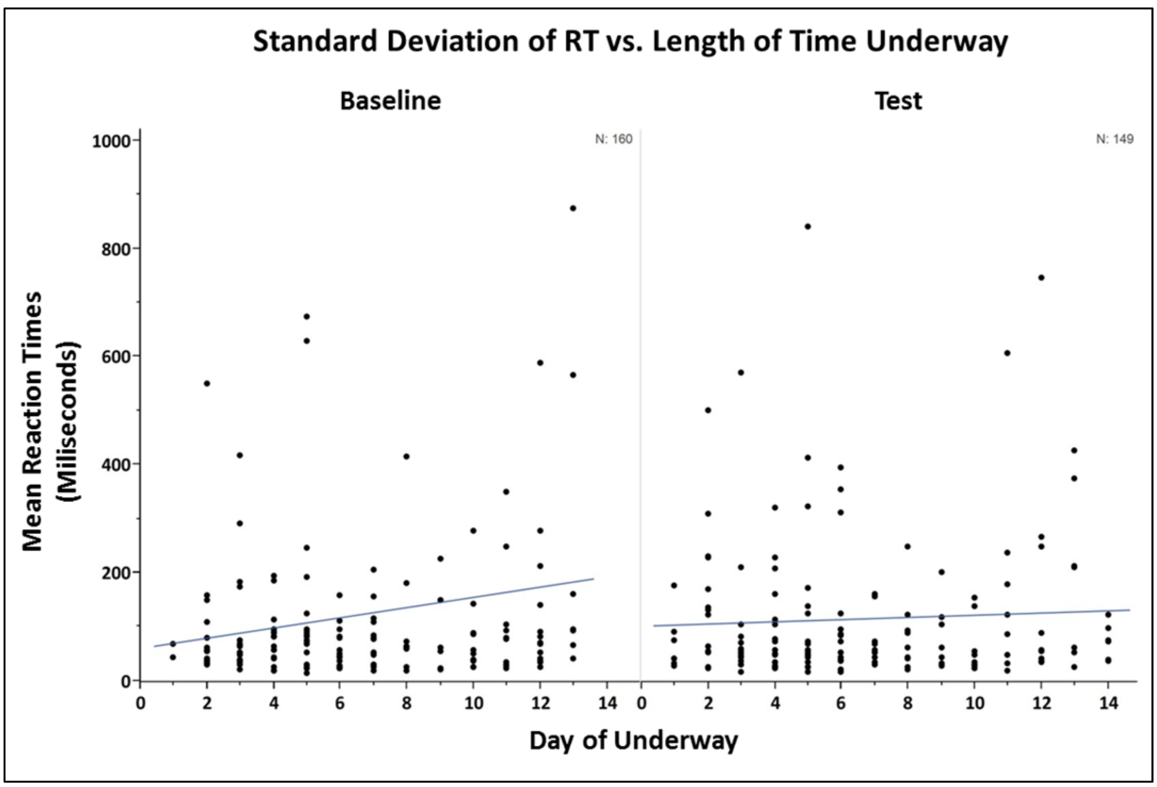

Figure 30. Standard Deviation of RT vs. Length of Time Underway

As with the Mean RT, a comparison of the SDRT by watch interval was done to see how the time of day affected the variability of watchstander performance. Another two-sample t-test was used to accomplish this with a null hypothesis assuming there was no difference. The results of these comparisons can be seen in Table 8.

Watch Interval	t-value	p-value	Degrees of Freedom	Baseline Mean	Test Mean
1	2.0058	0.0522*	37.119	121.8387	70.0833
2	-1.6146	0.1124	52.383	139.5455	241.9355
3	1.6799	0.1034	29.917	278.8333	87.7273
4	1.7779	0.0825*	42.942	165.3514	64.0000
5	0.0901	0.9286	48.897	109.2703	105.7222

Table 10. Welch Two-Sample t-Test Comparisons of SDRTs

It is clear to see from the results in Table 8 that the null was rejected for watch interval one and four, indicating there was a significant difference in the SDRT for personnel standing the night watches and the afternoon watches on the 3/9-rotation. This indicates that personnel had more consistent performance during the night watches and during the afternoon watches. Figure 31 shows a series of boxplots of the SDRT for each of the watch intervals broken down by the two underway periods. Looking at the boxplots for intervals one and four allow you to see the decrease in variance found in Table 8.

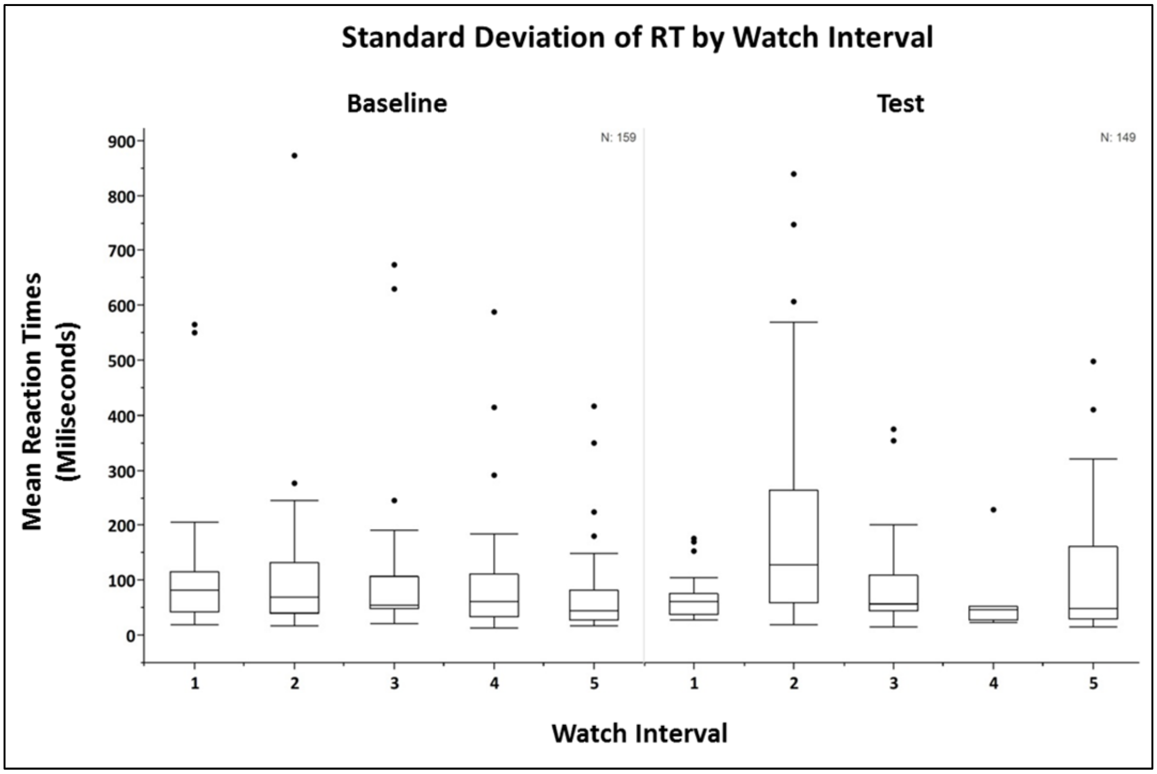

Figure 31. Standard Deviation of RT by Watch Interval

3. Examination of PVT Lapses (Lapses)

Another measure of vigilance in personnel is the lapses of attention accrued during each PVT. Higher Lapse rates could possibly be an indication of low vigilance due to inattentiveness. As with the Mean RT and SDRT, the first step was to compare the average number of lapses for each individual on both periods. Figure 32 shows the difference in the average number of lapses for each individual. It shows nine of the 15 participants experienced a drop in the average number of PVT lapses on the 3/9-rotation.

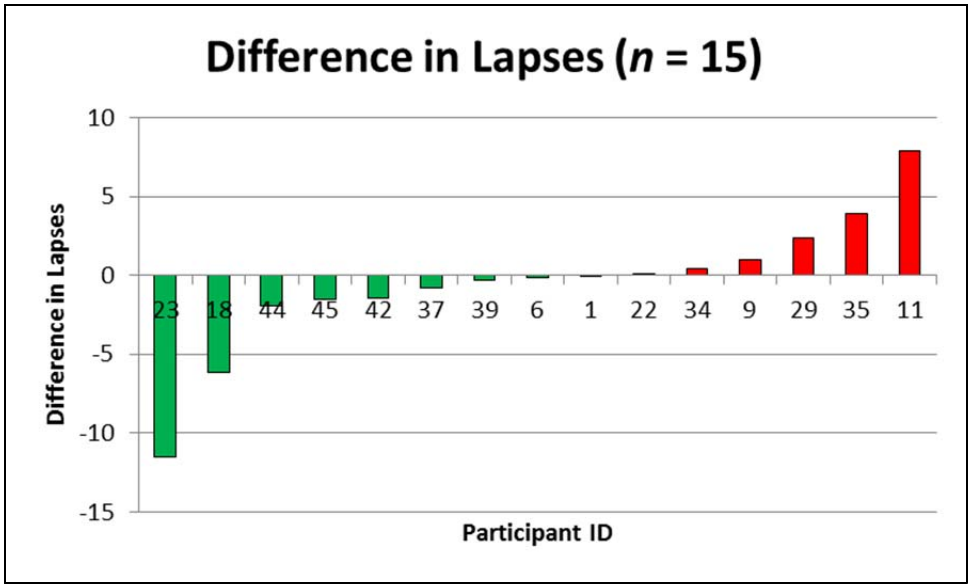

Figure 32. Difference in Lapses

While Figure 32 appears to show an improvement in the number of lapses, a paired t-test comparing these values failed to reject the null hypothesis. It could not be conclusively confirmed whether or not there was a difference in the average number of lapses between the baseline and test period.

A plot of the number of lapses over time, in Figure 35, shows that under both the 5/15 and 3/9, personnel appeared to have an increasing number of lapses per test as time increased. The linear regression line, using length of time underway as the primary regressor plotted over the baseline, had a p-value of 0.0035. This indicates that time was a significant factor in determining the number of Lapses. The p-value for the line on the test period 0.1478, so time was not a significant regressor in determining lapses for the 3/9.

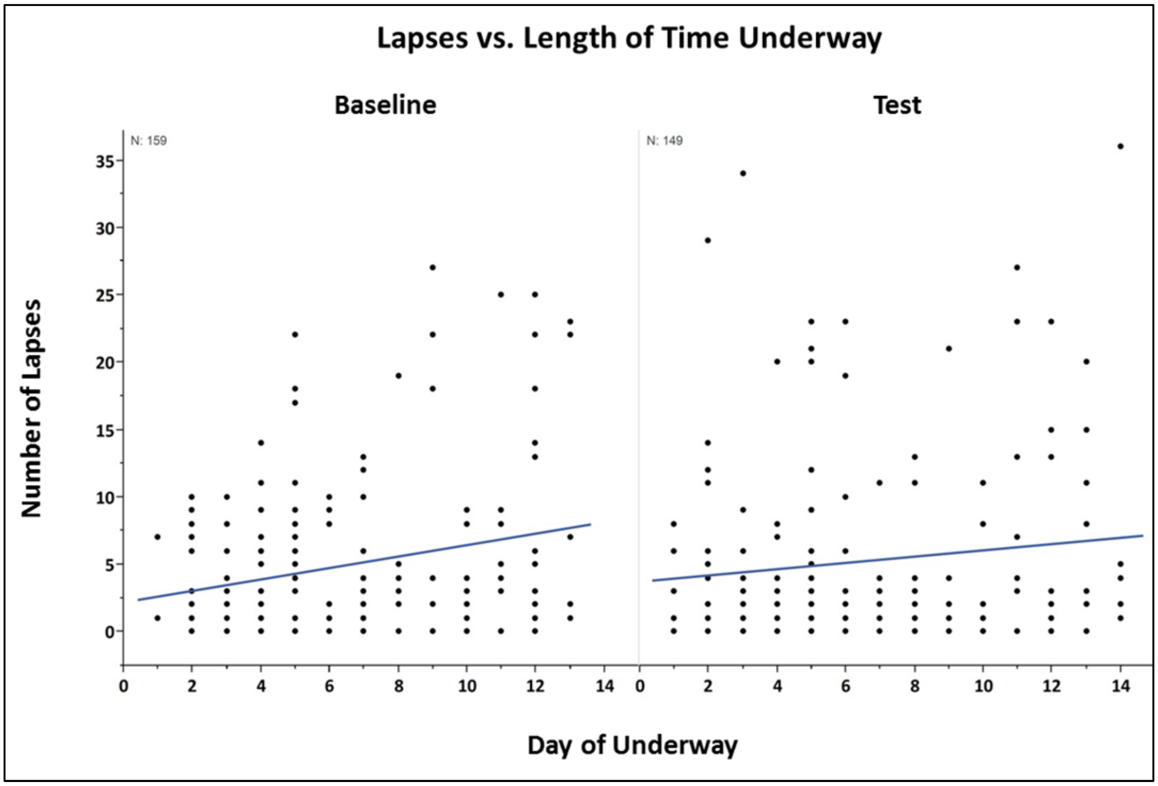

Figure 33. Lapses vs. Length of Time Underway

Figure 34 shows a series of boxplots of the lapses of all PVT tests during each of the watch intervals for both underways. In this figure, it appears that the total number of lapses for watch interval one, three and four are lower during the test period. A two-sample test, assuming there was no difference in the number of lapses, confirmed that there was a difference in watch interval one and four, but not three. Results of these tests can be seen in Table 9.

Watch Interval	t-value	p-value	Degrees of Freedom	Baseline Mean	Test Mean
1	2.1216	0.0403*	39.092	7.0000	3.4166
2	-0.9641	0.3388	60.028	7.3939	9.5483
3	0.078	0.9381	60.753	5.0000	4.8484
4	2.5811	0.0134*	42.429	6.4864	2.1250
5	0.1073	0.9148	73.341	4.8108	4.6481

Table 11. Welch Two-Sample t-Test Comparisons of PVT Lapses

D. COMPARISON OF PSYCHOMOTOR VIGILANCE TESTING AND ACTIGRAPHY DATA

In order to determine if the predicted effectiveness changes correlated with the actual performance differences seen in the PVT data, the actigraphy data was analyzed with the PVT data. This analysis focused on comparing how PE and actual performance changed together. It was expected that as PE increased an improvement in the PVT performance relative to the changes would also be seen.

The first metric analyzed against the PE of each individual was the Mean RT. Figure 34 shows a plot of the Mean RT for each PVT test on the baseline and test period against PE. The actigraphy data for each individual, on both the baseline and test periods, was run through the FAST, which calculated the PE for each person at all times of both underways. Using the time and date from each PVT test, the PE for an individual participant at the moment in time the PVT was administered could be derived.

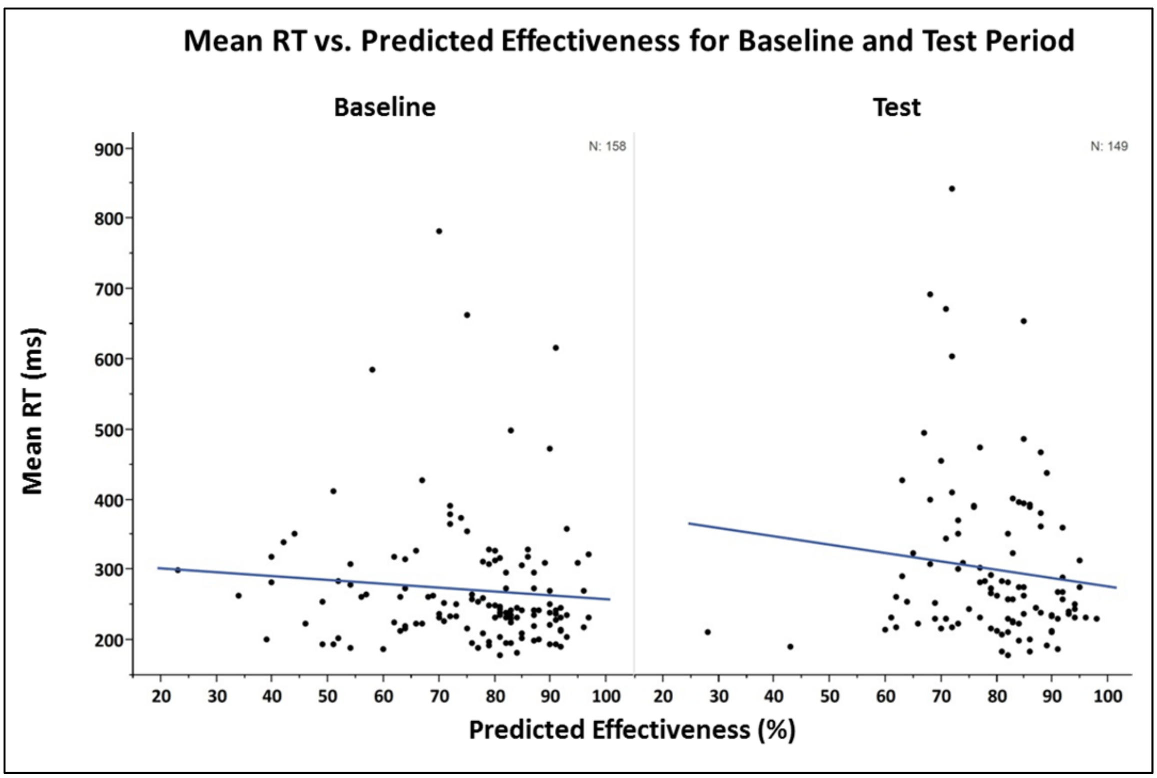

Figure 34. Mean RT vs. Predicted Effectiveness for Baseline and Test Period

Looking at the data in Figure 34, it appears that Mean RTs decrease as PE increases. A linear regression line was calculated and plotted over the data using PE as the only regressor. The coefficient of PE on the baseline regression was -0.5488, while the coefficient of PE on the test period regression was -1.1895. This suggests that as PE increased, Mean RT decreased twice as fast on the 3/9 than on the 5/15. One data point in the baseline period initially appeared to have a strong influencing effect on this regression because the PE for this point was less than 25%. A sensitivity analysis examining the effect of removing this data point did not significantly change the coefficients and thus was kept in the analysis.

Figure 35 shows the SDRT plotted against PE. This figure shows that on the 3/9-rotation, personnel variability in RTs decreased with increasing PE. It also shows that on the 5/15 rotation, personnel had no change in SDRT with changing PE.

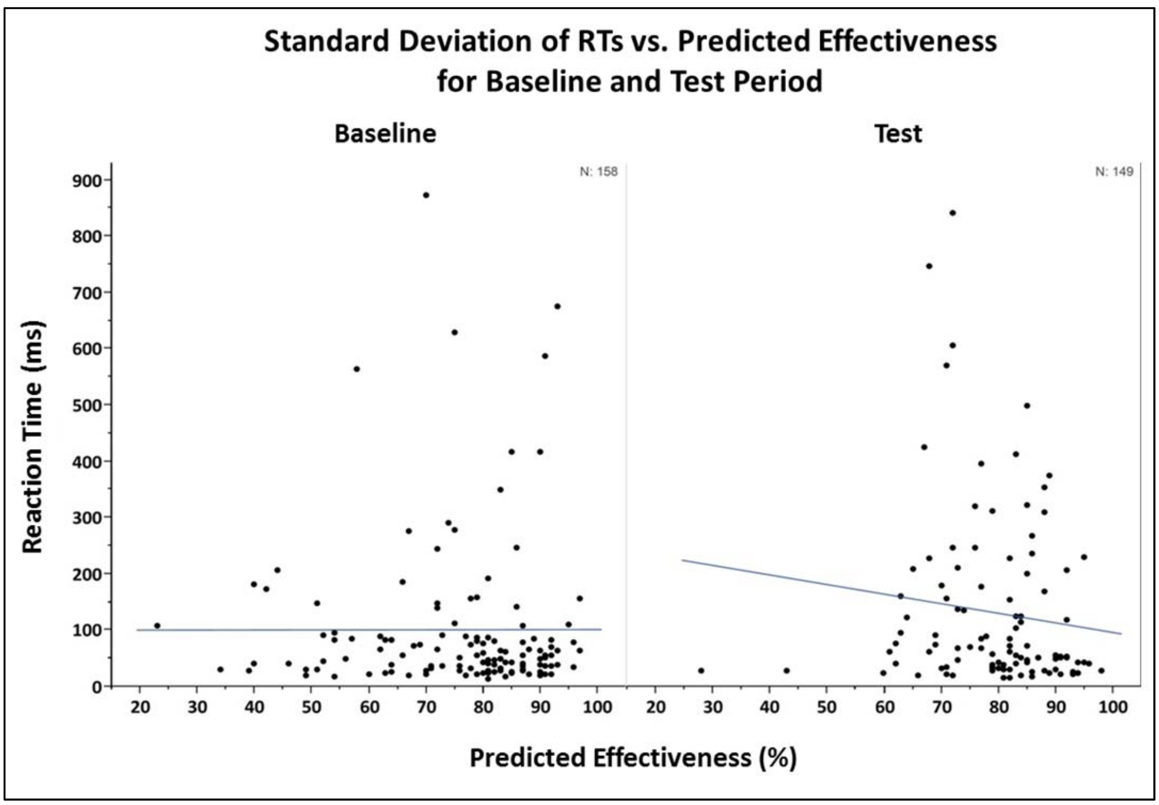

Figure 35. Standard Deviation of RTs vs. Predicted Effectiveness for Baseline and Test Period

Looking at the SDRT versus PE by watch intervals shows how the SDRTs changed between each interval on the two underway periods. This information is shown in Figure 36. This figure shows that personnel on watch intervals one and two during the baseline period had consistently lower PEs than those on the other watch intervals. This is not surprising given that intervals one and two correspond to the late night and early morning watch rotations, when personnel are most likely to be fatigued. What's interesting to see is how the groupings changed for both intervals one and two during the test period. It appears that, again, all personnel standing watch at these times on the 3/9 had PEs at or above 60%.

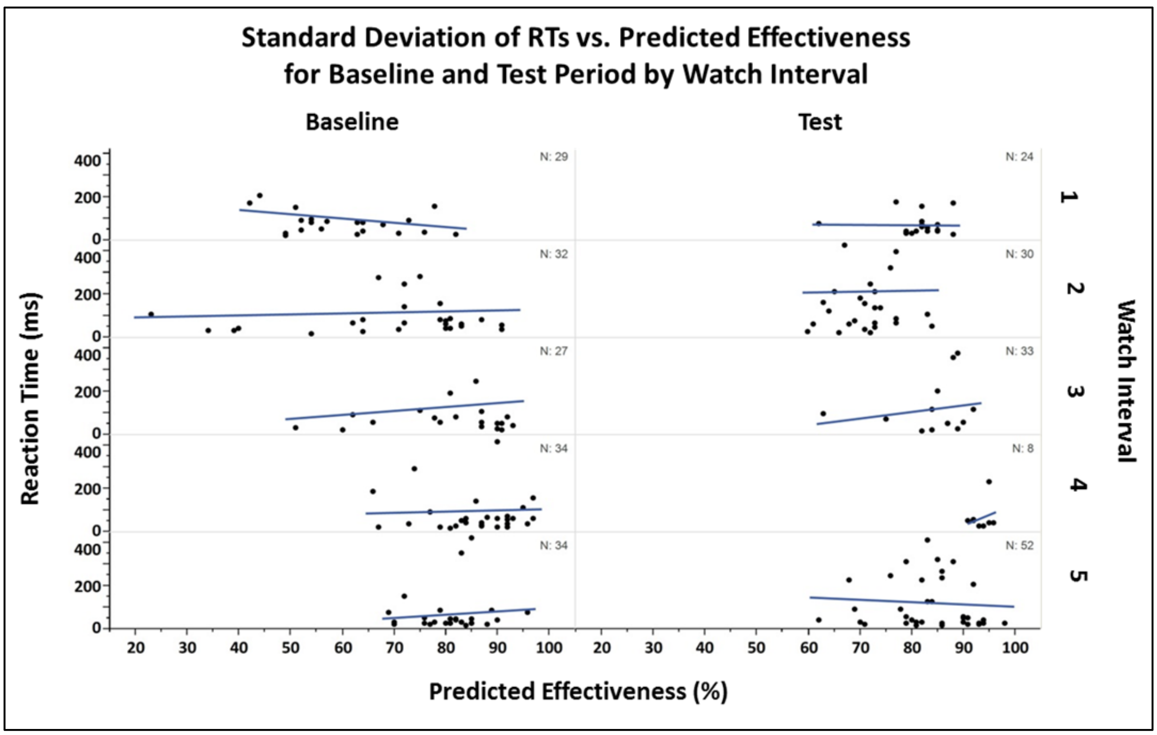

Figure 36. Standard Deviation of RTs vs. Predicted Effectiveness for Baseline and Test Period by Watch Interval

The final PVT metric examined against PE was the number of lapses per test. Figure 37 shows how the lapses changed with increasing PE for each watch interval on both underway periods. It shows the same basic trends that were seen in Figure 36.

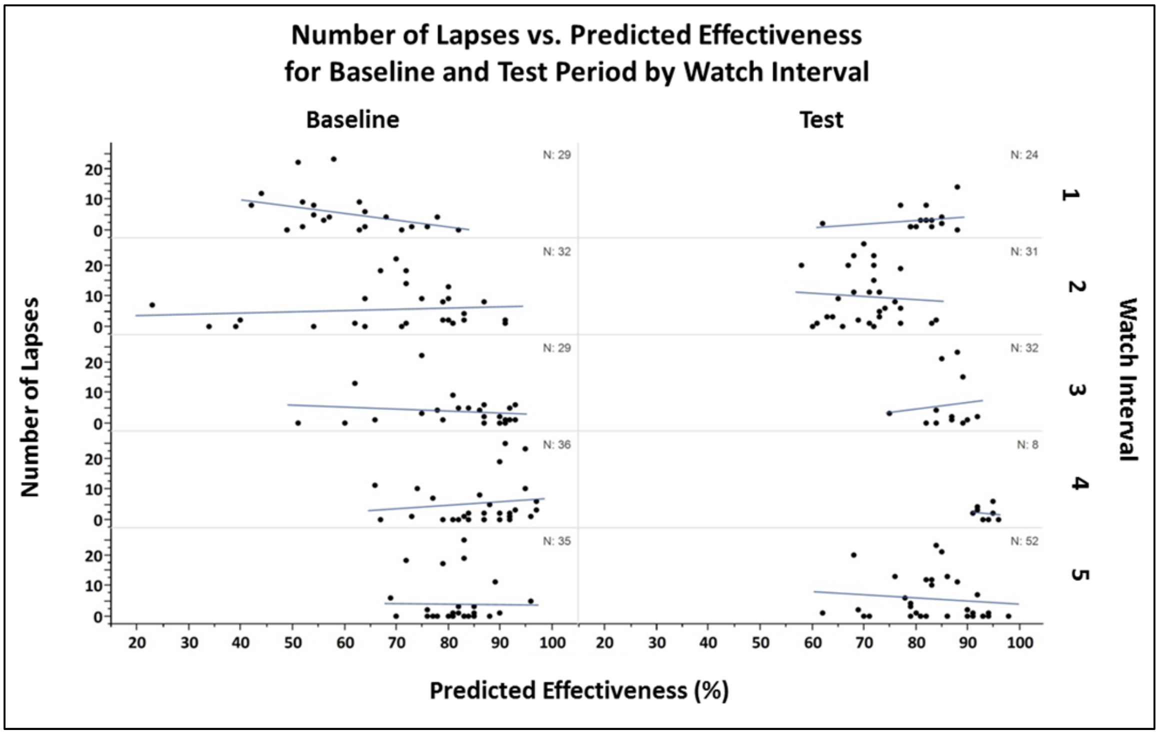

Figure 37. Number of Lapses vs. Predicted Effectiveness for Baseline and Test Period by Watch Interval

V. CONCLUSIONS AND RECOMMENDATIONS

A. DISCUSSION OF RESULTS

Many different metrics were used to try to quantify the benefits of the alternative 3/9-watch rotations compared to the traditional 5/15-rotation. These metrics consisted of subjective surveys and objective psychomotor vigilance tests (PVTs) as well as actigraphy data from wrist activity monitors (WAMs). All of these metrics provided slightly different views of the effects of sleep deprivation on watch standers and each one also provided insight into how changes in the watch rotations affected the individual and their performance.

Measuring human performance is challenging and no one measurement method is sufficient to capture human performance in its entirety. The majority of the test participants self-reported favoring the 3/9-watch rotation on the surveys and believed it provided more opportunities for rest. The 3/9-rotation was clearly preferred to the conventional 5/15 four-section counterpart. Based solely on the results of the survey data, the 3/9-rotation should be seriously considered for implementation onboard ships as an alternative to traditional watches. Personnel felt the 3/9-rotation was superior to traditional watches in terms of more sleep and having a better opportunity to develop SA prior to assuming the watch—both of which are needed to improve performance.

If watchstanders are unable to attain the required levels of sleep for their cognitive abilities to operate at peak performance, they will never be able to fully gain situational awareness (SA) because their cognitive reasoning skills and memory are seriously impacted, as previously shown in the literature review. This problem continues to compound throughout the watch period because the individual continues to develop a larger sleep debt that is not properly remedied. At the same time, individual attentiveness begins to wane drastically as the length of the watch increases. All of these are factors of sleep deprivations that can ultimately lead to watchstanders not only feeling underprepared for watch, but legitimately impaired in their watchstanding competency.

When personnel were asked whether they felt they had proper time to develop SA on both rotations, nearly all participants felt they had a better opportunity to develop SA on the 3/9 compared to the 5/15.

Failure on the part of a watchstander to develop SA can quickly lead to loss of watch information and gaps in attention to the situation at hand—a serious concern when operating a warship at sea. The information gathered from the survey data suggests concern should be given to whether or not the traditional 5/15 watch rotation allows watchstanders the ability to develop proper SA. This inability could be largely attributed to sleep deprivation.

Analysis of the actigraphy data showed personnel did receive more sleep on the 3/9 than the 5/15. The average amount of sleep per day on the 5/15 was 5.56 hours, while the average sleep on the 3/9 was 6.11. An examination of the difference in average amount of sleep for each individual revealed that there was a significant statistical difference in the amount of sleep received on the 3/9 than on the 5/15. This analysis was completed using a significance level of 0.1 because of the low number of test subjects and the nature of field data collection. It is believed that with a higher *n* value or greater control during the data collection, significance in results could be seen with a significance level of 0.05. Further research is needed in this regard to confirm, or refute, the results seen in this study.

While a difference in sleep was noted, it should also be noted that some participants did receive less sleep on the 3/9, as was seen in Figure 21. The reason some participants received less sleep can be attributed to changes in the ship's operating schedule. Between the two underway periods the ship conducted different types of operations that require different personnel to be more actively engaged than others. For this reason, some crewmembers may have been more actively engaged at different times, which could result in less sleep for some. Regardless, it was shown that, overall, personnel received more sleep on the 3/9 than the 5/15.

Analysis of the sleep data also indicated personnel had, on average, a higher predicted effectiveness (PE) as a result of more consistent sleep patterns. So, while the

total amount of sleep gained may not improve much for each person, more consistent sleep patterns were seen by nearly all participants while using the alternative 3/9-watch rotation. This is most probably a result of circadian rhythm. These consistent work patterns are just as important as the total amount of sleep gained because they allowed personnel to have higher PE, despite receiving less sleep. From this perspective, it is actually reasonable to say that personnel do not necessarily require more sleep to perform better because the consistent sleep patterns help compensate for less sleep.

A look at the relationship between the difference in sleep and the effects on PE in Figure 23 revealed that a positive difference in the change of the amount of sleep had a large impact on the change in PE. The actograms for each participant showed that the biggest influence on the higher PEs was probably the consistent sleep patterns. Consistency in sleep is influential in cognitive performance, as previously mentioned in the literature review. Personnel who are able to receive consistent sleep are likely to have higher cognitive performance. Looking at the actograms, such as those in Figures 26 and 27, it was clear that all participants received the benefit of these consistent sleep patterns. Personnel operating on the 3/9 consistently had PE value at or above the 60% level, well above PE levels seen on the 5/15.

Examining the performance metrics, PVT data revealed that some watch standers experienced measurable improvement in performance. Paired t-tests were inconclusive in supporting the claim that personnel had “better” performance on the 3/9-rotation. A plot of the change in mean reaction times (Mean RT) over time, in Figure 27, suggested that as the length of the time underway increased, personnel performance worsened on both the baseline and test periods. On the 5/15-rotation, this worsening of performance could be attributed to the increasing sleep debt personnel received as a result of inconsistent sleep. In fact, the regression analysis for this said that for every increase in one day of underway time, personnel were predicted to perform 9.87 milliseconds worse than the day before. During the test period personnel were predicted to perform only 2.94 milliseconds as bad for every day underway. Clearly the sleep debt is still a factor in influencing performance on the 3/9, but it does not appear to be as strong of an

influencer. Because of this, the analysis completed is inconclusive in confirming any difference in Mean RTs between the two watch rotations.

A further examination into the actual times each day the PVTs were taken, though, indicated that there was a significant difference in performance on the night watches, the mid-morning watches and the afternoon watches. Personnel standing watch during these times did experience better performance on the 3/9 than on the 5/15. This indicates that personnel standing watch during these times were more vigilant and attentive at the end of their watches than they were on the 5/15. This is an extremely positive sign that the 3/9 benefited the watchstanders. It also shows how time of day can have a significant impact on performance and alertness, regardless of the amount of sleep received. Some watch intervals saw no change in performance across the two watch rotations because the time of day naturally allowed personnel to perform the same.

Analysis of Mean RTs in conjunction with PE showed that, as expected, when PE increased in personnel, their Mean RTs improved. This result was seen in both underway periods and underscores the need to ensure personnel are operating at peak performance. Allowing personnel the opportunity to rest allows them to operate more effectively and thus they perform better.

Unlike Mean RTs, the standard deviation of reaction times (SDRT) had a noticeable difference in nearly all participants between the two underways. This time the paired t-tests supported the claim that personnel had more consistent performance on the 3/9. Looking again at the impact of time on SDRT, in Figure 30, showed that SDRT worsened with time on the 5/15, but did not appear to worsen significantly on the 3/9. Two-sample comparisons of the SDRTs for all PVTs in specific watch intervals also revealed that personnel standing the night watches and the afternoon watches performed with greater consistency. So, not only did Mean RT improve, but consistency in watchstander performance also improved during the night and afternoon watch periods.

Improvements in the night watch performance could, again, be directly attributed to more or better quality rest. Once personnel are able to adapt to the static watch times, they are able to perform better during periods that would normally be marked by lower

performance. This is a result of the circadian rhythm of personnel adjusting to their work/rest patterns. The more consistent performance during the afternoon watch may at first seem surprising, but it should not be. Nearly everyone experiences a mid-afternoon “dip” in performance and alertness because of their circadian rhythm. Personnel who are standing watch on the 3/9 during what would be their normal “dip” period have, again, adjusted to this watch time due to the static nature of the rotation. Because they have adjusted to it, the effects of the dip in performance are not as severe as they would have been on the 5/15 when they were constantly rotating.

The effects of PE on SDRT were slightly different than the effects seen on Mean RTs. Personnel had consistent performance regardless of PE on the 5/15, but had better performance with higher PE on the 3/9. This is a possible indicator that personnel standing watch on the 5/15 will have roughly the same level of consistency despite the fact that they may be getting more sleep. This could be a result of the inconsistent sleep patterns and the fact that personnel are not actually receiving the quality rest needed to perform better. Looking again at how consistent personnel performed on the various watch intervals with increasing PE did not yield any significant results based on PE, but it did show that on the late night and early morning watches, personnel operated on higher PE levels and had fairly consistent performance regardless of PE.

A decrease in the total number of lapses indicates that personnel are more attentive to their task. Since human vigilance wanes consistently as time increases, having a higher vigilance at the end of their watch periods implies personnel maintain a higher level of vigilance during their watch. This was one of the ultimate goals of the alternative 3/9-rotation, to provide a way for personnel to maintain higher vigilance throughout their watch. When personnel are standing watch, it is critical that they not fail to quickly and accurately identify potentially time sensitive pieces of information. A lapse in identification can lead to a dangerous situation for a ship. If personnel are not attentive to the situations at hand or are unable to accurately identify dangerous conditions in a timely manner, it could lead to an inability to respond as need to threats. Providing a watch environment where personnel are less likely to have a lapse is therefore critical to shipboard safety and defense.

Looking at the change in lapses between the two underways initially revealed no differences. While nine of the 15 participants did have, on average, lower number of lapses, paired t-tests were unable to confirm there was a statistically significant difference. Looking at lapses over time did again indicate that with increasing time underway, personnel were more likely to have a lapse in performance on the 5/15, but not on the 3/9. Keeping in line with the results seen in both the Mean RTs and SDRTs, the number of lapses was also significantly different for personnel standing the night and afternoon watches on both underways. Again, personnel standing watch during these times had fewer lapses on the 3/9, than the 5/15. The number of lapses per watch interval on both underways showed that similar results as those seen for SDRTs. Essentially personnel had consistent lapses on the 3/9 regardless of PE.

Together, all of this information paints a favorable picture for adoption of the 3/9-watch rotation onboard ships. While not everyone experienced the same benefits uniformly for all performance metrics, the fact that personnel did receive more sleep quantity and consistency is enough to support the 3/9. The differences that were seen in personnel performance can be attributed to the differences in people themselves. Individual motivation has a significant influence on total performance; however, the measurable changes in performance for personnel in this study solidifies the necessity for replacing the traditional 5/15 with an alternative such as the 3/9.

B. RECOMMENDATIONS FOR OPERATIONAL IMPLEMENTATION OF ALTERNATIVE WATCH ROTATIONS

For commanders who wish to use these rotations onboard their ships, it is vital that they do it correctly. Simply changing watch rotations without giving due consideration for the impacts on the rest of the ships daily schedule will not yield the benefits seen in this study. Careful planning on the part of the leadership of JASON DUNHAM went into ensuring the alternative watch rotations could be used in conjunction with the daily routine. The daily routine was altered by the command with little input from the research team. This ensured the needs of the ship were met without being negatively impacted by the watch rotations.

In order to facilitate the watch schedule changes, the ship adjusted both the breakfast and dinner meal hours to line-up with the watch rotation periods. This forced the breakfast meal to be served 30-minutes sooner and the evening meal to be served one-hour later. Both of these changes were well received by the crew. The ship also moved the usual "morning meetings" such as Executive Officer's Call, Department Head Call, and Quarters from the morning to immediately after lunch. This provided the night watchstanders an opportunity for "late sleepers" in the morning to ensure they received an equal opportunity for sleep as the rest of the crew. This too was very well received.

LT Bobby Rowden, the Operations Officer for JASON DUNHAM, is responsible for the ship's schedule and is one of the senior Department Heads onboard. LT Rowden commented on his perception of the benefits of this schedule.

> This schedule was challenging at first for the divisions. It was good, however, in that it forced the DIVOs and Chiefs to think beyond today. Since we weren't meeting in the morning each day, the divisions wouldn't receive a lot of tasking until after lunch, but this caused the DIVOs to be constantly thinking about what was going to have to happen tomorrow morning without my telling them what to do in the morning… If I have to be thinking 30 days out, then the least they can do is think 24 hours out so, that's one reason why I think it's a good schedule.

A similar sentiment was shared by the ships Weapons Officer, who personally liked the 3/9-rotation and felt that the benefits of the schedule outweighed the negatives associated with having to modify the schedule.

For commanders adopting either of these alternative rotations, it is highly recommended that they consider adjusting the daily schedule in a manner similar to the JASON DUNHAM. Figure 38 shows a copy of a typical JASON DUNHAM Plan of the Day (POD) schedule from the baseline period compared to a typical POD from the test period. It should be noted that implementing the 3/9-rotation in conjunction with other traditional three and two-section rotations—5/10, 6/12, 6/6, etc.—can be facilitated with relative ease and without the need for major schedule changes. Using the 4/8 in conjunction with other rotations is, however, more difficult and does require significant schedule modifications. The reason the 3/9 works better is because of how the time between the watches is divided out. Since a complete 3/9 cycle is exactly 12 hours and

each individual watch period is only three hours long, it is more adaptable to the traditional watch rotations that follow similar time patterns. While the 4/8 also follows a 12-hour cycle, having each watch be four hours in length creates less flexibility in managing it with other traditional watches. Figure 6 showed how both the 3/9 and 4/8 rotations where oriented in this study, but other configurations can be achieved with a little planning and flexibility on the part of a ship.

Even with the effective planning ahead of time, some concerns did arise from the alteration of the daily schedule. It was noted afterwards that certain daily activities, such as the Daily Operations Brief, were routinely missed by the watchstanders who stood the static 3/9 and 4/8 watch. Since these watchstanders stood the same watch time each day, they were unable to attend the daily brief, which was also held at the same time each day. Briefings such as this are important for command leadership to ensure that key personnel are kept aware of upcoming ship maneuvers and operations. In order to mitigate personnel missing these briefs, it was recommended by the leadership of DDG-109 that the time of the daily brief be alternated each day. By having the brief at two distinctly different times every other day—such as having the brief alternate between the morning and evening—it would ensure that no single watch team would miss the brief by more than one day.

USS JASON DUNHAM Plan of the Day Schedules

Sample Baseline Schedule

0600	REVEILLE
0600 – 0700	BREAKFAST
0630	SWEEPERS
0700 – 0800	XO's HAPPY HOUR (CLEANING STATIONS)
0700 – 1200	.50 CAL SHOOT
0730	DH CALL
0745	KHAKI CALL
0800	QUARTERS
0800 – 0900	MOB D: DC DRILLS
0800 – 1100	USW SCENARIO
0830 – 0930	3M TRNG
0930 – 1030	3M TEST
1000 – 1100	JO TRNG
1000 – 1100	XO INSPECTION OF MESSING & BERTHING
1100 – 1130	SWEEPERS
1130 – 1230	LUNCH
1200 – 1400	CAREER DEVELOPMENT BOARD
1230 – 1330	CLEANING STATIONS
1300 – 1330	CO SPOT CHECK
1300 – 1400	PT: INSANITY
1300 – 1430	PB4T
1300 – 1600	ORTSTAR TESTING
1430 – 1700	ZONE INSPECTIONS
1530 – 1600	SWEEPERS
1630 – 1730	DINNER
1730 – 1930	CSOSS: CSSCE DRILLS
1730 – 1930	MOB E: EVS/DRILLS
1830 – 1930	DAILY OPS BRIEF
1900 – 2000	PT: INSANITY
1930 – 2000	8 O'CLOCK REPORTS
2000 – 2100	PT: ZUMBA
2030	SWEEPERS
2100 – 2200	PT: INSANITY
2200	TAPS

Sample Test Period Schedule

0530 - 0630	BREAKFAST
0600	REVEILLE
0630	SWEEPERS
0700 – 1100	E4 ADVANCEMENT EXAM
0700 – 1200	SLAMEX
0800	CSG 8 COMMS CHECKS
0800 - 1000	USW: PARR SCENARIOS
0900 – 1000	MONIES AUDIT BOARDS (MWR)
0930 – 1000	HEALTH PROMOTION BOARD
0930 – 1030	3M TEST
1000 – 1100	XO MESSING & BERTHING INSPECTION
1000 – 1100	ALL OFFICER/SECTION LEADER TRAINING
1100 - 1130	SWEEPERS
1130 – 1230	LUNCH
1230	DH CALL
1230	FLIGHT QUARTERS
1300	QUARTERS
1300 – 1330	CO SPOT CHECK
1300 – 1400	PB4T
1330 – 1500	ASTAC TRNG OPS
1300 – 1500	VERTREP/DLQs/RLQs
1330 – 1430	XO'S HAPPY HOUR
1330 – 1500	MISSILEX REHEARSAL
1400 – 1530	CPO 365
1530 – 1630	DAILY OPS BRIEF
1500 – 1700	HAVEQUICK
1500 – 1700	MOB E: EVS/DRILLS
1530	SWEEPERS
1600 – 1800	HIFR/VERTREP
1730 – 1830	DINNER
1800	RHIB PAXFER
1830 – 2030	USW: PARR SCENARIOS
1830 – 2100	WILL WORKSHOP
1900 – 2300	DLQ/RLQ
2030	SWEEPERS
2200	TAPS

Figure 38. USS JASON DUNHAM Sample POD Schedules for the Baseline and Test Periods

There will always be issues that arise with any schedule and changing that schedule in itself creates new issues. Commanders need to remember that having an open

mind to change is essential to implementing changes like these and it will take work on the part of command leadership to provide the positive reinforcement needed for success of these alternative schedules.

C. RECOMMENDATIONS FOR FUTURE WORK

Continuing research is currently underway onboard the JASON DUNHAM and will help in providing more data to support or refute the use of alternative watch rotations. This new research will attempt to quantify the long-term benefits of the 3/9-watch schedule. Further studies replicating this research should be performed onboard every type of surface ship platform possible to assess whether these benefits are translatable to larger and smaller classes of ships. It would be of particular interest to see how such rotations could be implemented onboard the new classes of Littoral Combat Ship, since these ships have dramatically lower manning levels than other surface ships.

A more in-depth analysis also needs to be conducted on the Engineering watchstanders. While it was not discussed in this thesis, data collected on engineering watchstanders seemed to be widely disparate from the other watchstanders in the study. The performance of the Engineers was, on average, significantly worse than those seen in Bridge and Combat Information Center (CIC) watchstanders. As a result, questions are left open with regard to the cause of such radically different PVT performance from these personnel. A dedicated study should be conducted to look more in-depth at the Engineering watchstanders. An examination of possible correlations between the performance of Engineers and recruitment or training metrics should also be examined. Work also needs to be done to determine how different the workloads of these individuals are compared to the Bridge, CIC and Lookout watchstanders who are standing the same watch rotations. It is plausible that a fundamentally different set of responsibilities could lead to reduced long-term performance due to more demanding job requirements.

This study did not survey or monitor any personnel from the ship’s supply department purely based on the fact that these individuals do not stand watches in the same manner as other sailors. These individuals do, however, provide a much needed support aspect to all shipboard operations and knowing how these alternative watch

rotations impact their daily operations would be of great interest. It is of particular interest to know how changes in the meal schedules affected the daily sleep and work-rest patterns of the Supply department personnel.

D. CONCLUSION

This study began with four major objectives, (1) to determine the optimal method of implementing an alternative watch rotation to facilitate forward rotation; (2) determine if it is possible to assess vigilance and attention of personnel on these alternative watch rotations; (3) assess whether or not the performance of individuals improved using the proposed alternative watch rotations as compared to a traditional rotation; and (4) to ascertain crew preferences to watch rotations.

This study was not successful in determining the optimal manner of facilitating a forward rotation in an alternative watch schedule. Due to the short nature of both underway periods, only 14 days each, they were not long enough to accurately measure whether rotating the alternative watch forward or backwards was best because personnel did not actually rotate on either the 3/9 or 4/8-rotations. It is still believed that a forward rotation is best based on the results of previous research (Roberts, 2012). Roberts predicted higher performance for personnel, based on optimizing watch rotations, utilizing the forward rotation. His claim could not be supported based on this study, but should be examined more closely to confirm previous research analysis.

Overall, the study was largely successful in achieving the other three goals. It was possible to measure the attentiveness of the various watchstanders through the use of PVTs. These results provide both positive support for and negative results against use of alternative watch rotations. The PVT results did not clearly identify changes in the individuals, but they did find differences in larger groups of watchstanders. The participants of the study overwhelmingly supported the use of the alternative 3/9-rotation instead of a traditional 5/15, which achieved the last goal of this study.

Though the data collected may not irrefutably support the need for a rotation such as the 3/9, implementing such a rotation onboard U.S. Navy surface ships is a step in the right direction toward changing traditional mindsets about watch rotations. The Navy has

been operating ships at sea for nearly 237 years, but what has made the U.S. Navy great is its ability to adapt to change. Its ability to remain flexible and embrace new technologies and frames of mind has allowed the U.S. Navy to continue being a world leader in naval power for two centuries.

A simple change in the way the surface community does business, such as the one proposed by this study, is achieved through a simple change in thinking. Commanders who are willing to try something different is what makes our Navy great and this is simply an extension of that ingenuity. It requires nothing more and nothing less than the individual initiative of ship captains. Regardless of the results seen in the data collected, changes such as this should be embraced and thought threw before being discarded.

APPENDIX A. NPS CONSENT TO PARTICIPATE IN RESEARCH

Introduction. You are invited to participate in a research study entitled ***Analysis of the Effects of Sleep Deprivation on U.S. Navy Surface Ship Watchstander Performance Using Alternative Watch Schedules***. The purpose of the research is to determine if, through the use of alternative watch scheduling, the individual performance of U.S. Naval personnel standing watches onboard ships can be improved. This study is designed to ascertain the impact on an individual's vigilance and overall performance in the ability to stand watch by using a new watch rotation plan.

Procedures.
During the course of this study you will be asked to participate in the following activities:

- Complete hand written surveys assessing your individual sleep habits and predispositions prior to each underway. (This survey should take approximately 10-minutes to complete)
- Complete hand written surveys assessing your personal feelings and attitude toward various watch standing schedules and the differences between them prior to and after completion of the underway periods. (This survey should take approximately 10-minutes to complete)
- Complete hand written daily activity logs to record your overall daily activity patterns. (These logs should be periodically updated throughout the course of each day of the study, but should take no more than 10-minutes each day to complete)
- Wear wrist activity monitors during the duration of the study (except during shower periods) to record your daily rest/work patterns
- Complete a three minute psycho-motor vigilance test at the completion of each watch you stand underway
- Complete hand written surveys assessing your level of sleepiness prior to and immediately after each watch you stand. (This survey should take no more than one-minute to complete each time)

The requirements listed above are purely for research purposes and serve no purpose other than this study. At no point will your individual responses or data be shared with any individual outside of the research team and at no point will you be directly associated with the results. At no point will you be required to participate in audio or video recordings.

Approximately 40 personnel are expected to participate in this study, so there should be no concern about your individual results being singled out from the others.

Location. The interview/survey/experiment will take place onboard the USS JASON DUNHAM (DDG 109) during a normal underway period.

Cost. There is no cost to participate in this research study.

Voluntary Nature of the Study. Your participation in this study is strictly voluntary. If you choose to participate you can change your mind at any time and withdraw from the study. You will not be penalized in any way or lose any benefits to which you would otherwise be entitled if you choose not to participate in this study or to withdraw. The alternative to participating in the research is to not participate in the research.

Potential Risks and Discomforts. The potential risks of participating in this study are:
- Inconvenience associated with taking time to fill out required surveys and logs

- Inconvenience of having to complete psycho-motor vigilance testing immediately after watch periods
- There may be slight discomfort with wearing the wrist activity monitors, but no more than would be associated with wearing a wrist watch
- There is a minimal risk of breach of confidentiality with the surveys and data collected

Anticipated Benefits. Anticipated benefits from this study are the potential for immediate change to existing U.S. Navy watch scheduling. There is no direct benefit to you for participating in this study.

Compensation for Participation. No tangible compensation will be given.

Confidentiality & Privacy Act. Any information that is obtained during this study will be kept confidential to the full extent permitted by law. All efforts, within reason, will be made to keep your personal information in your research record confidential but total confidentiality cannot be guaranteed. All participants will be issued an identification number that will be used to track individual surveys and data collected. At no point will your name be directly linked with any specific piece of information collected. All names recorded will be maintained separate from the actual data and all information, including data collected, will be maintained only by the researcher.

Points of Contact. If you have any questions or comments about the research, or you experience an injury or have questions about any discomforts that you experience while taking part in this study please contact the Principal Investigator, Dr. Nita Lewis Shattuck, 831-656-2281, nlshattu@nps.edu. Questions about your rights as a research subject or any other concerns may be addressed to the Navy Postgraduate School IRB Chair, CAPT John Schmidt, USN, 831-656-3864, jkschmid@nps.edu.

Statement of Consent. I have read the information provided above. I have been given the opportunity to ask questions and all the questions have been answered to my satisfaction. I have been provided a copy of this form for my records and I agree to participate in this study. I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

Participant's Signature Date

Researcher's Signature Date

APPENDIX B. BASELINE PRE-UNDERWAY PARTICIPANT SURVEY

1. Demographic information

Rate/Rank_________

2. Is this your first time underway? (Check One)

______ Yes
______ No
If No, how many years of sea time have you had in the Navy? _________

3. Have you stood watch underway prior to this upcoming underway period? (Check One)

______ Yes
______ No -***If no, you may stop this survey now. Please turn in the survey materials. Thank you for your participation.***

4. Where are you standing watch during this underway? (Check one)

______ Bridge (Including lookouts)
______ CIC
______ CCS

5. Underway watch locations I have worked other than the one I am standing during this underway (Check all that apply)

______ Bridge (Including Lookouts)
______ SSES
______ Radio
______ CIC
______ Sonar
______ Engineering (Any engineering watch station)
______ Other (please specify)__________________________

6. What watch rotations have you stood before this underway? (Check all that apply)

______ Two section (port and starboard)
______ Three section (five and dimes)
______ Four section
______ Five section

______ Other (please specify) ____________________________

7. What watch rotation will you be standing during this underway?

______ Two section (port and starboard)
______ Three section (five and dimes)
______ Four section
______ Five section
______ Other (please specify) ____________________________

8. The amount of rest/off-time you anticipate receiving, using your planned watch rotation, during this underway is: (Check one)

_____ much less than needed
_____ slightly less than needed
_____ about right
_____ more than needed
_____ too much

9. The amount of rest/off-time you anticipate other Sailors, standing a watch rotation different than your own, will receive during this underway is: (Check one)

_____ much less than needed
_____ less than needed
_____ about right
_____ more than needed
_____ too much

10. In your experience, using your planed watch rotation, do you anticipate having adequate time to develop proper situational awareness prior to assuming the watch? (check one)

________ Yes
________ No

11. Three things you <u>like</u> about your current watch rotation:

1.
2.
3.

12. Three things you <u>do not like</u> about your current watch rotation:

1.
2.
3.

13. What are the challenges you anticipate facing in adjusting to your planned watch rotation?

____

____

____

____

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APPENDIX C. BASELINE POST-UNDERWAY PARTICIPANT SURVEY

1. The amount of rest/off-time you received during this underway was: (Check one)

_____ much less than needed
_____ slightly less than needed
_____ about right
_____ more than needed
_____ too much

2. The amount of rest/off-time you believe other Sailors received, in comparison to your own, during this underway was: (Check one)

_____ much less than mine
_____ less than mine
_____ about the same
_____ more than mine
_____ much more than mine

3. Do you feel you had adequate time to develop proper situational awareness prior to assuming the watch during this underway period? (check one)

________ Yes
________ No

4. Three things you <u>liked</u> about the watch rotation you used during this underway:

1.
2.
3.

5. Three things you <u>disliked</u> about the watch rotation you used during this underway:

1.
2.
3.

6. What are the challenges you faced in adjusting to your watch rotation?

____

_

APPENDIX D. TEST POST-UNDERWAY PARTICIPANT SURVEY

1. Which alternative watch schedule did you use during this underway? (Circle one)

3/9 (Four-section) → Continue to question 2
4/8 (Three-section) → Skip to question 10

2. For the following questions, you will compare the 3/9 watch experience to other watches you have stood.

I found:

The 3/9 to be worse than the 5-10 hour “5 and dime”______
The 3/9 to be better than the 5-10 hour “5 and dime”______
The 3/9 to be the same as the 5-10 hour “5 and dime”______
No opinion or have not worked 5-10 hour watch (please specify)____________________

I found:

The 3/9 to be worse than the 5-15_____
The 3/9 to be better than the 5-15_____
The 3/9 to be the same as the 5-15_____
No opinion or have not worked 5-15 hour watch (please specify)___________________

I found:

The 3/9 to be worse than a “dog” watch_____
The 3/9 to be better than a “dog” watch _____
The 3/9 to be the same as a “dog” watch _____
No opinion or have not worked a “dog” watch (please specify)____________________

I found:

The 3/9 to be worse than the 4/8 _____
The 3/9 to be better than the 4/8 _____
The 3/9 to be the same as the 4/8 _____
No opinion or have not worked 4/8 hour watch (please specify)____________________

I found:

The 3/9 to be worse than the 6/12 _____
The 3/9 to be better than the 6/12 ______
The 3/9 to be the same as the 6/12_____
No opinion or have not worked 6/12 hour watch (please specify)___________________

I found:

The 3/9 to be worse than the 6/6 _____
The 3/9 to be better than the 6/6 ______
The 3/9 to be the same as the 6/6_____
No opinion or have not worked 6/6 hour watch (please specify)___________________

3. Did the 3/9 watchbill provide you with more opportunity for rest than other watchbills?

_______ Yes
_______ No   If no, please explain why:_______________________________

4. The amount of rest I received on the 3/9 watchbill was: (Check one)

______ much less than needed
______ less than needed
______ about right
______ more than needed

5. The rest received by other Sailors, both on and not on the same watch rotation as myself, during this underway seemed: (Check one)

______ much less than needed
______ less than needed
______ about right
______ more than needed

6. I had adequate time to develop situational awareness standing the 3/9 watch. (circle one)

Agree   Disagree

7. The top 3 things I <u>liked</u> about the 3/9 watchbill:

1.
2.
3.

8. Three things I <u>did not like</u> about the 3/9 watchbill:

1.
2.
3.

9. What were the challenges you faced in adjusting to the current 3/9 watch?

____
____
____
____

3/9 Watch Standers STOP HERE!!!!

10. For the following questions, you will compare the 4/8 (three-section) watch experience to other watches you have stood.

I found:

The 4/8 to be worse than the 5-10 hour "5 and dime"______
The 4/8 to be better than the 5-10 hour "5 and dime"______
The 4/8 to be the same as the 5-10 hour "5 and dime"______
No opinion or have not worked the 5-10 hour watch (please specify)_________________

I found:

The 4/8 to be worse than the 5-15_____
The 4/8 to be better than the 5-15_____
The 4/8 to be the same as the 5-15_____
No opinion or have not worked 5-15 hour watch (please specify)___________________

I found:

The 4/8 to be worse than a "dog" watch_____
The 4/8 to be better than a "dog" watch _____
The 4/8 to be the same as a "dog" watch _____
No opinion or have not worked a "dog" watch (please specify)_____________________

I found:

The 4/8 to be worse than the 3/9 _____
The 4/8 to be better than the 3/9 _____
The 4/8 to be the same as the 3/9 _____
No opinion or have not worked 4/8 hour watch (please specify)____________________

I found:

The 4/8 to be worse than the 6/12 _____
The 4/8 to be better than the 6/12 ______
The 4/8 to be the same as the 6/12_____
No opinion or have not worked 6/12 hour watch (please specify)___________________

I found:

The 4/8 to be worse than the 6/6 _____
The 4/8 to be better than the 6/6 ______
The 4/8 to be the same as the 6/6_____
No opinion or have not worked 6/6 hour watch (please specify)____________________

11. Did the 4/8 watchbill provide you with more opportunity for rest than other watchbills?

______ Yes
______ No If no, please explain why:___________________________________

12. The amount of rest I received on the 4/8 watchbill was: (Check one)

_____ much less than needed

_____ less than needed
_____ about right
_____ more than needed

13. The rest received by other Sailors, both on and not on the same watch rotation as myself, during this underway seemed: (Check one)

_____ much less than needed
_____ less than needed
_____ about right
_____ more than needed

14. I had adequate time to develop situational awareness standing the 4/8 four-section watch. (circle one)

Agree Disagree

15. The top 3 things I liked about the 4/8 watchbill:

1.
2.
3.

16. Three things I did not like about the 4/8 watchbill:

1.
2.
3.

17. What were the challenges you faced in adjusting to the current 4/8 four section watch?

APPENDIX E. EPWORTH SLEEP SCALE

This scale is designed to determine how likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired. This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to think about how they would have affected you. Use the following scale to choose the most appropriate number for each situation:

0 = no chance of dozing
1 = slight chance of dozing
2 = moderate chance of dozing
3 = high chance of dozing

SITUATION	CHANCE OF DOZING
Sitting and reading	_____________
Watching TV	_____________
Sitting inactive in a public place (e.g a theater or a meeting)	_____________
As a passenger in a car for an hour without a break	_____________
Lying down to rest in the afternoon when circumstances permit	_____________
Sitting and talking to someone	_____________
Sitting quietly after a lunch without alcohol	_____________
In a car, while stopped for a few minutes in traffic	_____________

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APPENDIX F. STANFORD SLEEPINESS SCALE

This is a quick way to assess how alert you are feeling. If it is during the day when you go about your business, ideally you would want a rating of a one. Take into account that most people have two peak times of alertness daily, at about 9 a.m. and 9 p.m. Alertness wanes to its lowest point at around 3 p.m.; after that it begins to build again. Rate your alertness at different times during the day. If you go below a three when you should be feeling alert, this is an indication that you have a serious sleep debt and you need more sleep.

HOW AND WHEN TO COMPLETE SURVEY:

- **PLEASE CIRCLE THE RATING THAT MOST ACCURATELY REFLECTS YOUR LEVEL OF SLEEPINESS AT THE TIME YOU ARE COMPLETING THIS SURVEY**
- **PLEASE COMPLETE THIS SURVEY AT THE BEGINNING AND END OF EACH WATCH**

Degree of Sleepiness	**Scale Rating**
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	X

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APPENDIX G. PITTSBURG SLEEP QUALITY INDEX

INSTRUCTIONS:
The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, what time have you usually gone to bed at night?

BED TIME ___________

2. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

NUMBER OF MINUTES ___________

3. During the past month, what time have you usually gotten up in the morning?

GETTING UP TIME ___________

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

HOURS OF SLEEP PER NIGHT ___________

For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you . . .

a) Cannot get to sleep within 30 minutes

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

b) Wake up in the middle of the night or early morning

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

c) Have to get up to use the bathroom

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

d) Cannot breathe comfortably

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

e) Cough or snore loudly

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

f) Feel too cold

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

g) Feel too hot

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

h) Had bad dreams

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

i) Have pain

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

j) Other reason(s), please describe____

____

How often during the past month have you had trouble sleeping because of this?

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

6. During the past month, how would you rate your sleep quality overall?

Very good ___________

Fairly good ___________

Fairly bad ___________

Very bad ___________

7. During the past month, how often have you taken medicine to help you sleep (prescribed or "over the counter")?

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

No problem at all __________

Only a very slight problem __________

Somewhat of a problem __________

A very big problem __________

10. Do you have a bed partner or room mate?

No bed partner or room mate __________

Partner/room mate in other room __________

Partner in same room, but not same bed __________

Partner in same bed __________

If you have a room mate or bed partner, ask him/her how often in the past month you have had . . .

a) Loud snoring

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

b) Long pauses between breaths while asleep

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

c) Legs twitching or jerking while you sleep

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

d) Episodes of disorientation or confusion during sleep

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

e) Other restlessness while you sleep; please describe ___________________________

____

Not during the past month_____ Less than once a week_____ Once or twice a week_____ Three or more times a week_____

APPENDIX H. PITTSBURG SLEEP QUALITY INDEX SCORING GUIDE

<u>Form Administration Instructions</u>

The range of values for questions 5 through 10 are all 0 to 3.

Questions 1 through 9 are not allowed to be missing except as noted below. If these questions are missing then any scores calculated using missing questions are also missing. Thus it is important to make sure that all questions 1 through 9 have been answered.

In the event that a range is given for an answer (for example, '30 to 60' is written as the answer to Q2, minutes to fall asleep), split the difference and enter 45.

<u>Reference</u>

Buysse DJ, Reynolds CF, Monk TH, Berman SR, Kupfer DJ: The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. Psychiatry Research 28:193-213, 1989.

<u>Scores—reportable in publications</u>

On May 20, 2005, on the instruction of Dr. Daniel J. Buysse, the scoring of the PSQI was changed to set the score for Q5J to 0 if either the comment or the value was missing. This may reduce the DISTB score by 1 point and the PSQI Total Score by 1 point.

PSQIDURAT-DURATION OF SLEEP

IF Q4 > 7, THEN set value to 0

IF Q4 < 7 and > 6, THEN set value to 1

IF Q4 < 6 and > 5, THEN set value to 2

IF Q4 < 5, THEN set value to 3

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQIDISTB- SLEEP DISTURBANCE

IF Q5b + Q5c + Q5d + Q5e + Q5f + Q5g + Q5h + Q5i + Q5j (IF Q5JCOM is null or Q5j is null, set the value of Q5j to 0) = 0, THEN set value to 0

IF Q5b + Q5c + Q5d + Q5e + Q5f + Q5g + Q5h + Q5i + Q5j (IF Q5JCOM is null or Q5j is null, set the value of Q5j to 0) > 1 and < 9, THEN set value to 1

IF Q5b + Q5c + Q5d + Q5e + Q5f + Q5g + Q5h + Q5i + Q5j (IF Q5JCOM is null or Q5j is null, set the value of Q5j to 0) > 9 and < 18, THEN set value to 2

IF Q5b + Q5c + Q5d + Q5e + Q5f + Q5g + Q5h + Q5i + Q5j (IF Q5JCOM is null or Q5j is null, set the value of Q5j to 0) > 18, THEN set value to 3

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQILATEN-SLEEP LATENCY

First, recode Q2 into Q2new thusly:

IF Q2 > 0 and < 15, THEN set value of Q2new to 0

IF Q2 > 15 and < 30, THEN set value of Q2new to 1

IF Q2 > 30 and < 60, THEN set value of Q2new to 2

IF Q2 > 60, THEN set value of Q2new to 3

Next

IF Q5a + Q2new = 0, THEN set value to 0

IF Q5a + Q2new > 1 and < 2, THEN set value to 1

IF Q5a + Q2new > 3 and < 4, THEN set value to 2

IF Q5a + Q2new > 5 and < 6, THEN set value to 3

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQIDAYDYS- DAY DYSFUNCTION DUE TO SLEEPINESS

IF Q8 + Q9 = 0, THEN set value to 0

IF Q8 + Q9 > 1 and < 2, THEN set value to 1

IF Q8 + Q9 > 3 and < 4, THEN set value to 2

IF Q8 + Q9 > 5 and < 6, THEN set value to 3

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQIHSE- SLEEP EFFICIENCY

Diffsec = Difference in seconds between day and time of day Q1 and day Q3

Diffhour = Absolute value of diffsec / 3600

newtib =IF diffhour > 24, then newtib = diffhour – 24

IF diffhour < 24, THEN newtib = diffhour

(NOTE, THE ABOVE JUST CALCULATES THE HOURS BETWEEN GNT (Q1) AND GMT (Q3))

tmphse = (Q4 / newtib) * 100

IF tmphse > 85, THEN set value to 0

IF tmphse < 85 and > 75, THEN set value to 1

IF tmphse < 75 and > 65, THEN set value to 2

IF tmphse < 65, THEN set value to 3

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQISLPQUAL- OVERALL SLEEP QUALITY

Q6

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQIMEDS- NEED MEDS TO SLEEP

Q7

Minimum Score = 0 (better); Maximum Score = 3 (worse)

PSQI TOTAL

DURAT + DISTB + LATEN + DAYDYS + HSE + SLPQUAL + MEDS

Minimum Score = 0 (better); Maximum Score = 21 (worse)

<u>Interpretation</u>: TOTAL < 5 associated with good sleep quality

TOTAL > 5 associated with poor sleep quality

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